THE UNIVERSITY OF UTAH

July 23, 1996

Mr. Wayne Hedberg, Permit Supervisor
Division of Oil, Gas and Mining
State of Utah
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

Dear Wayne:

Enclosed is a copy of the report due to you from the biosolids study at Kennecott. As you can see from the attached copy of the letter that I had sent to Lisa Rogers, the biosolids have made a significant difference when compared to the other methods of reclamation employed there. I plan to initiate parts of the microbiology study on the impoundment next fall.

If you would like to discuss any part of this report with me, please give me a call at (801) 585-3029. Let me know when you plan to visit.

Sincerely,

Rich

R. L. McNearny, Ph.D.
Assistant Professor

Enclosures

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313 W.C. Browning Building
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mineeng@mines.utah.edu

THE UNIVERSITY OF UTAH

July 23, 1996

RECEIVED
JUL 29 1996
DIV. OF OIL, GAS & MINING

Ms. Lisa Rogers
State of Utah
Division of Water Quality
P. O. Box 144870
Salt Lake City, Utah 84114-4870

Dear Lisa:

Enclosed for your consideration are two copies of the second report from the Kennecott Utah Copper biosolids study at the tailings impoundment near Magna. Copies of this report will also be submitted to Bob Brobst at EPA and to Wayne Hedberg at DOGM. This report is also submitted to you as an annual for Kennecott Utah Copper Corporation, as is required of them. Further, submittal of this report to you satisfies the final requirements of state contract 95 1470.

Current observations from the study are favorable. Observation of the biosolids-amended plots have shown that they are withstanding the current dry summer much better than other areas on the impoundment. Plant growth on all the test plots is substantial. Last year's dominant species (winter rye) has been essentially replaced by sheep fescue, tall wheatgrass and by legumes, indicating ecological succession has been successfully initiated. Ecological succession is necessary if a self-sustaining climax ecosystem is to be established on the impoundment.

Sincerely,

Rich

R. L. McNearny, Ph.D.
Assistant Professor

Enclosures

cc: Bob Brobst, U.S. Environmental Protection Agency
Wayne Hedberg, Division of Oil, Gas and Mining
Sonya Wallace, Division of Water Quality

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THE UNIVERSITY OF UTAH

DEMONSTRATION PROJECT

FOR

THE APPLICATION OF MUNICIPAL BIOSOLIDS TO THE KENNECOTT TAILINGS IMPOUNDMENT

Annual Report Submitted to

Division of Water Quality,
Department of Environmental Quality, and
Division of Oil, Gas and Mining,
Department of Natural Resources,
State of Utah

July 6, 1996

for the Kennecott Utah Copper Corporation

by

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Table of Contents

Table of Contents (continued)

1 Executive Summary

Five separate test sites were established in 1994 to evaluate the use of municipal sewage sludge as a soil amendment and conditioner (hereafter referred to as "biosolids") on the Kennecott Utah Copper Corporation's tailings impoundment near Magna, Utah. Two additional sites were added in 1995. Each site was divided into 16 test plots to evaluate four replications of the four rates of biosolids addition and incorporation into the tailings. The 1994 sites were labeled as sites No. 1, 2, 3, 3B, and 4. The 1995 sites were labeled as sites No. 6 and 7. Site No. 5 was dropped from the study after the 1995 sites were laid-out and marked.

Site No. 1 was treated with $CaCO_3$ to evaluate performance in acidity neutralization and Site No. 3 was treated with wood residues to evaluate the effect of an additional carbon source. On site No. 6, three plots were added in which tilling was not performed to evaluate the effect of this practice.

Except for site No. 7, the rates of biosolids application were 0 (as a control plot), 10, 20 and 30 dry tons/acre. On site No. 7, the rates of biosolids application were 0, 20, 30, 45 plus 15 tons of wood residues, and 60 dry tons of biosolids/acre plus 30 tons/acre of wood residues.

The sites were monitored for potential leaching of total heavy metals as required under 40 CFR 503, agronomic (or soil-building) properties, total metals, extractable metals (or metals generally available for uptake by plants), plant tissue analysis for heavy metals, biomass production, percent cover and plant species diversity. Beginning in the summer of 1996, monitoring of microbial soil-building properties will begin.

This research is being conducted under an agreement with the State of Utah (Division of Oil, Gas and Mining and the Division of Water Quality) and the U.S. Environmental Protection Agency (EPA). Kennecott received approval from the State on March 31, 1994 and from the EPA on April 4, 1994. Approval for this project from EPA was required by the 40 CFR 503 because the biosolids were applied at higher than agronomic rates. This research and demonstration project will provide the data necessary to justify the use of biosolids at higher than agronomic rates if Kennecott should later decide to utilize biosolids to a greater extent than at the present on the tailings impoundment. The research is significant because of its scale and scope - nearly 100 acres of land are evaluated under semi-arid conditions.

This report presents the results of the first year of the project to include a comparison of baseline properties monitoring versus changes in the properties after one growing season. The project will also perform comparisons after second, third, fifth and tenth growing seasons.

All agronomic properties of the tailings improved with biosolids addition. Significant improvements were seen when comparing the control plots to all treated plots. Generally, improvements increased linearly with increasing biosolids addition. There was a significant increase in the level of nitrate in the tailings, as would be expected. Further monitoring of this anion is warranted.

Leaching of both extractable and total metals from the addition of biosolids was not observed. This conclusion is drawn from evaluation of tailings samples taken at depth, the resin capsule data and the lysimeter data. Given the results after the first growing season, a recommendation is made that sampling of tailings at depth for total metals be discontinued. Monitoring of metals at the 2-foot and 5-foot depths should still continue with both the resin capsules and the lysimeters. One additional instrumentation set in another control plot should be added because the current instrumentation set is located in an apparent acidified zone.

A statistically significant improvement in biomass production and percent cover by plant species occurred for all biosolids application rates when compared to the control plots. Both the 20 and 30 t/acre application rates produced significantly more plant biomass than the 10 t/acre application rate. All application rates of biosolids produced significantly more plant biomass than the control plots. The first year production was first dominated by winter rye, sheep fescue and tall wheatgrass, which are all annual grasses. Legume production did occur, but not at a significant level when compared to the annual grasses. The production of legume species is expected to increase in future years, however, as they should out-compete the grasses in the long-term. Consideration should be given to altering the seed mix to favor higher amounts of legume species.

Chemical analyses of all plant species tested indicated that metal tissue concentrations did not increase due to biosolids addition.

2 Current Status of the Project

1) Sites No. 1, 2, 3, 3B, and 4, 6 and 7 have been laid out and marked as given by the work plan. Site No. 5 was laid out and marked, but was later dropped from the study.
2) Baseline samples have been taken from all sites.
3) Biosolids application was completed on all sites.
    a) $CaCO_3$ was added to site No. 1 at the rate of 6 tons per acre prior to the application of biosolids.
    b) Sites No. 2, 4 and 6 received biosolids only.
    c) Site No. 3, prior to the application of biosolids, received wood residue at the rate of 30 tons/acre. In site No. 7, four test plots received 15 tons/acre of wood residue and four test plots received 30 tons/acre of wood residue.
    d) Biosolids from the Magna Wastewater Treatment Plant was applied to site No. 3B.
4) For sites No. 1 through 4, additional sampling for agronomic properties was completed in December 1994 and in the spring of 1995.
5) Sites No. 1 through 4 were planted in the early spring of 1995. Sites No. 6 and 7 were planted in the spring of 1996.
6) For sites 1 through 4, chemical and agronomic sampling was completed in the summer of 1995. This sampling program was accomplished to evaluate changes in tailings properties after the first growing season.
7) Two reports have been written, including this report.

3 Introduction

The biosolids demonstration project is a cooperative effort between Kennecott Utah Copper Corporation (KUCC), the Department of Mining Engineering of the University of Utah and the Central Valley Water Reclamation Facility (CVWRF). The purpose of this project is to evaluate the enhancement of vegetative growth after a one-time application of biosolids to the slopes of the KUCC tailings impoundment, near Magna, Utah (Fig. 1). Anaerobically digested (Class B) biosolids from the CVWRF was used as biosolids. The Magna Wastewater District also provided aerobically-treated (Class B) biosolids for one of the test sites. The test site tailings were sampled for metals and agronomic properties before and after the application of biosolids. The sites will be evaluated for 1, 2, 3, 5, and 10 years after the initial application for chemical and agronomic properties, biomass production and above ground species diversity. Additional monitoring of soil microbiology will begin the summer of 1996.

The primary permanent goal of managing the KUCC tailings impoundment is to diminish the environmental impact on the surrounding landscape by stabilizing the impoundment by vegetation. Vegetation is a cost-effective method of stabilizing the impoundment's surface. Vegetation reduces erosion, stabilizes the mine tailings and provides a quick cover prior to commencement of natural succession (Rafail and Vogel, 1978). But the enhancement of vegetation depends on the ability of the colonizing plant species to respond adequately with their roots and shoots to the physical structure and the chemical composition of the tailings. In order to overcome nutrient shortage and to condition the tailings, some sort of amendment is useful. The amendments may include inorganic fertilizers, fly ash, wood-residue, or biosolids. The project's experiments are designed to evaluate the effects of amendments of $CaCO_3$ plus biosolids, wood residues plus biosolids, and biosolids alone on the enhancement of the growth of vegetation.

Tailings amended with chemical fertilizers, unlike tailings amended with biosolids, require extensive time periods, often as long as 20 years, for the buildup of microbial populations, which is an indicator of biological activity in the soil/tailings profile as well as a significant indicator of

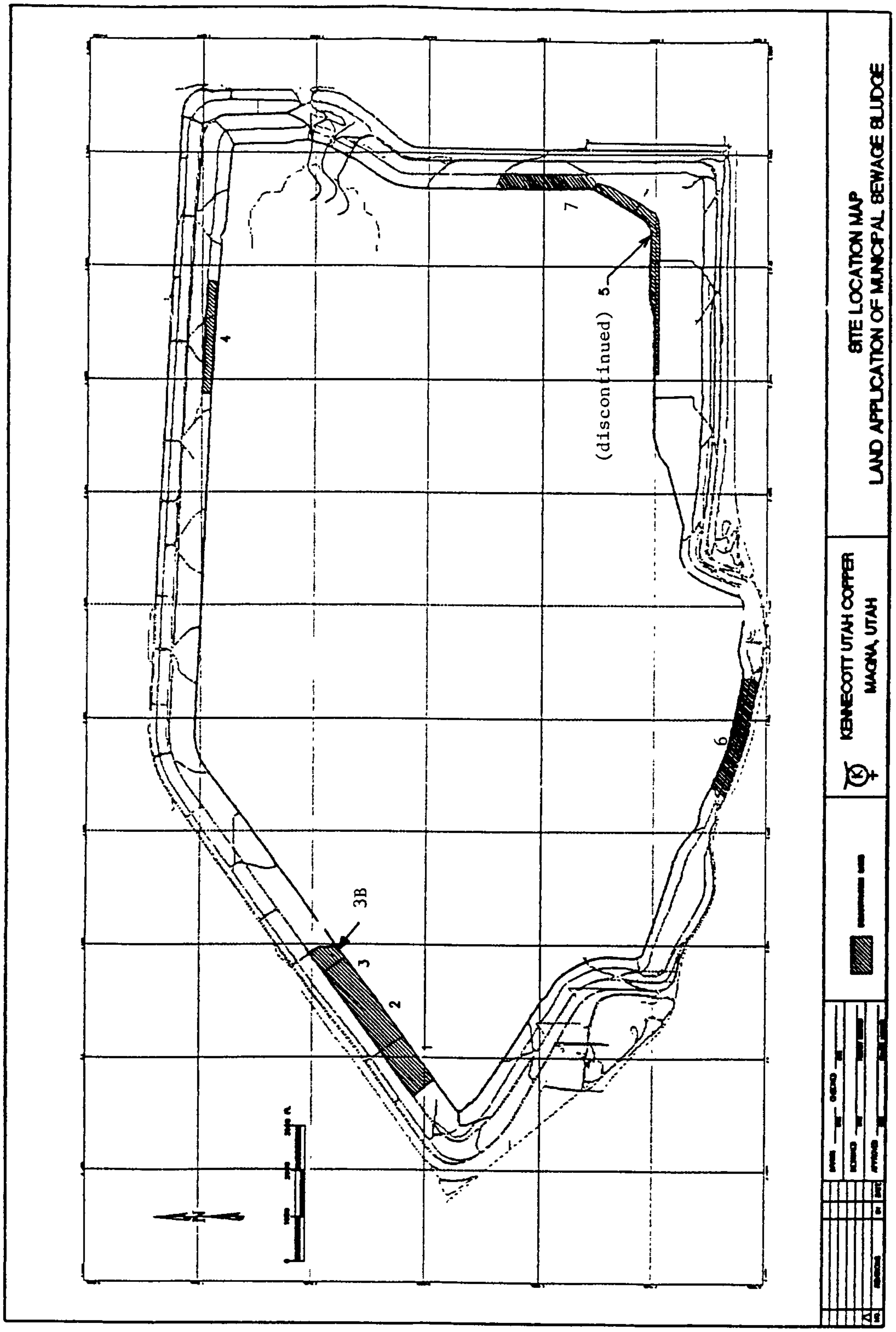


Figure 1 - KUCC Biosolids Demonstration Project

long-term reclamation success (Segal and Mancinelli, 1987). The use of biosolids is attractive because one waste could be used to ameliorate another. Extensive research has shown that stabilized municipal biosolids is an excellent tailings amendment and chemical fertilizer substitute. Successful establishment of forage species has occurred in the past directly on degraded land amended with biosolids (Munshower, 1994).

$CaCO_3$, as a limestone reject from the lime-slaking plants, was applied at the rate of 6 t/acre as an amendment to site No. 1, along with biosolids, to evaluate its effectiveness in addressing potential acidification issues. The amendment of $CaCO_3$ raises the pH and increases the calcium concentration. Doing this should also reduce heavy metal availability. Additionally, calcium would be recycled into the plant residues, and it could react with organic matter to form stable humate complexes (Munshower, 1983).

Wood residues, an excellent source of carbon, have been applied to Site No. 3 at the rate of 30 t/acre. Four test plots in site No. 7 received 15 tons/acre and four plots received 30 tons/acre. The addition of organic material such as wood residue can reduce evaporation and increase water infiltration and retention, but can have detrimental effects on plant growth by causing rapid utilization of inorganic nitrogen by microbes. Since wood residues and biosolids have opposite effects, putting them together in the tailings in the proper combination can resolve the problem of excessive nitrogen utilization. The biosolids should provide ample available nitrogen for plant growth as well as for wood material decomposition. Further, the wood should immobilize some of the excessive nitrogen resulting from the biosolids application. One difficulty, however, with the use of wood residues is high transport cost.

Thus, there are four classes of treatment applied to the test sites. They are: (1) a uniform application of $CaCO_3$ and four application rates of anaerobically-treated Central Water Reclamation Facility (CVWRF) biosolids (site No. 1), (2) a uniform application of wood residues and four application rates of CVWRF biosolids (sites No. 3 and 7), (3) four application rates of

CVWRF biosolids application (sites No. 2, 4 and 6), and (4) four application rates of aerobically-treated Magna biosolids (site No. 3b).

4 Purpose and Objectives of the Project

The objectives of the demonstration project are:

1. To evaluate the response of vegetation to changes in the physical, chemical and biological properties of the tailings after amendment with biosolids, $CaCO_3$ and wood residues.

2. To monitor the potential mobility of soluble metals in the applied biosolids.

3. To evaluate effects of treatments and amendments on plant growth and to develop specifications for the safe application of biosolids. The specifications will include biosolids application rates and monitoring requirements.

This report addresses the effects of biosolids alone (Sites No. 2, 3b and 4), biosolids plus $CaCO_3$ (Site No. 1), and biosolids plus wood chips (Site No. 3) on tailings agronomic properties, biomass production, percent plant cover, and plant tissue metal concentrations during the first growing season (1995). Additionally, this report discusses changes in total metals with depth and changes in metals with time as measured by unibest resin capsules and lysimeters.

5 Importance of this Project

In the past, research into the use of biosolids as a soil amendment has been conducted in humid climates, with very little research performed in the semi-arid climate that is typical of Utah. This project is a first of its kind in terms of scale and scope - almost 100 acres of land are being used as test sites.

6 U.S. EPA 40 CFR 503 Regulations

The Environmental Protection Agency published the final rules for the disposal of municipal biosolids on February 19, 1993 in the Federal Register, 40 CFR Parts 257, 403, and

503. These regulations were promulgated under authority of Sections 405 (d) and (e) of the Clean Water Act, as amended. One section of the regulations permits the application of sewage sludge to land for beneficial use (as biosolids), e.g., for land reclamation.

7 Biosolids - Characteristics

The CVWRF biosolids -as a dry belt filter press cake- was analyzed for the 40 CFR 503 regulated metals before and during application to the impoundment. Both analyses were based on average and maximum test results from January 3 to March 1, 1994. These analyses are given in the Interim Report (McNearny, 1995). Similar analyses were performed on the Magna biosolids. The Magna biosolids test results are also available in the Interim Report.

As calculated previously in the Interim Report (McNearny, 1995), the maximum calculated biosolids application rate for the CVWRF biosolids is 35.7 dry tons/acre. The maximum calculated biosolids rate for the Magna biosolids is 69.0 dry tons/acre. These application rates are based on the metals content of the biosolids. These calculated application rates are greater than the maximum rate of 30 dry tons/acre that was actually applied to the tailings impoundment. Thus, the application of biosolids was within the Table 4 limitations of 40 CFR 503.

An agronomic rate of 2.1 dry tons/acre was also calculated in the Interim Report. The agronomic rate is based on nitrogen requirements of the crop that will be grown on the impoundment. However, for reclamation purposes, a higher one-time application rate may be used.

Analyses for the regulated metals was performed on a continuing basis by CVWRF during the time of application of biosolids to the impoundment. The number of tests performed by CVWRF exceeded the number of tests required by 40 CFR 503. Table 1 lists the values for each of 40 CFR 503 metals as analyzed by CVWRF. *At no time were the regulatory limits exceeded.*

Table 1 - CVWRF Dry Belt Filter Press Cake Metal Data (ppm)

Date	As	Cd	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
1 Aug	5.8	5.1	141.9	504.9	3.0	57.5	57.6	230.6	11.2	1020.0
8 Aug	5.5	5.6	126.0	533.5	4.1	46.7	67.9	317.0	8.5	1041.7
10 Aug	0.8	5.1	100.9	473.9	2.6	45.3	54.3	308.2	--	831.3
15 Aug	2.6	6.8	126.6	520.9	2.6	46.5	--	301.0	8.7	953.2
22 Aug	2.9	6.8	112.4	581.9	3.2	43.8	--	308.0	15.8	1032.5
29 Aug	9.7	11.2	101.6	552.0	1.5	50.2	45.6	321.3	14.1	993.8
6 Sept	5.8	6.2	78.1	506.7	2.8	45.6	35.6	238.9	17.8	910.0
12 Sept	11.2	7.0	71.9	485.3	3.0	57.2	18.2	219.4	17.7	863.3
19 Sept	11.2	8.0	77.1	542.9	2.5	56.7	35.9	228.4	18.4	1011.5
26 Sept	4.1	5.8	84.3	586.6	1.6	59.7	66.3	264.2	15.2	1034.4
3 Oct	0.1	7.2	83.7	644.6	1.1	46.1	60.8	234.3	23.5	1235.0
10 Oct	4.6	5.7	62.1	552.9	1.1	47.4	55.8	204.4	11.9	1099.1
17 Oct	14.8	7.5	57.5	575.2	2.5	55.7	45.7	130.4	9.8	978.4
24 Oct	5.8	8.7	78.8	650.4	2.6	--	41.8	250.9	12.5	1422.8
Ave.	6.1	6.9	92.9	550.4	2.7	51.0	48.0	255.5	14.2	1030.5
Max.	*14.8*	*11.2*	*141.9*	*650.4*	*4.5*	*59.7*	*66.3*	*321.1*	*23.6*	*1422.8*
Min.	0.1	5.1	57.5	473.9	1.1	43.8	18.2	130.4	8.5	831.3
Limit	*75*	*85*	*3000*	*4300*	*57*	*75*	*420*	*840*	*100*	*7500*

8 Experimental Design

The experimental design consists of single-factor linear design that utilizes randomized complete plots for all the test sites. This design was chosen because of its suitability in reducing experimental error due to known sources of variation, e.g., variation in pH or other properties of the tailings across each test site. Each test site has been divided into plots of approximately one acre each. The width of each plot was kept close to 100 feet to facilitate biosolids application. The number of plots in each site is in a multiple of four. Thus, there generally are an equal number of test plots for each application rate, per site. Each test plot receives one of the four different application rates of biosolids, applied on a random basis, as given by Figures 2 through 7.

8.1 Project Site Descriptions and Locations

The KUCC tailings pond covers an area of approximately 5600 acres. All project sites are located on the slopes of the tailings impoundment. The property is fenced and locked from public access. The depth to the first major aquifer is 230 feet. The distance from the nearest drinking water well is one-quarter mile.

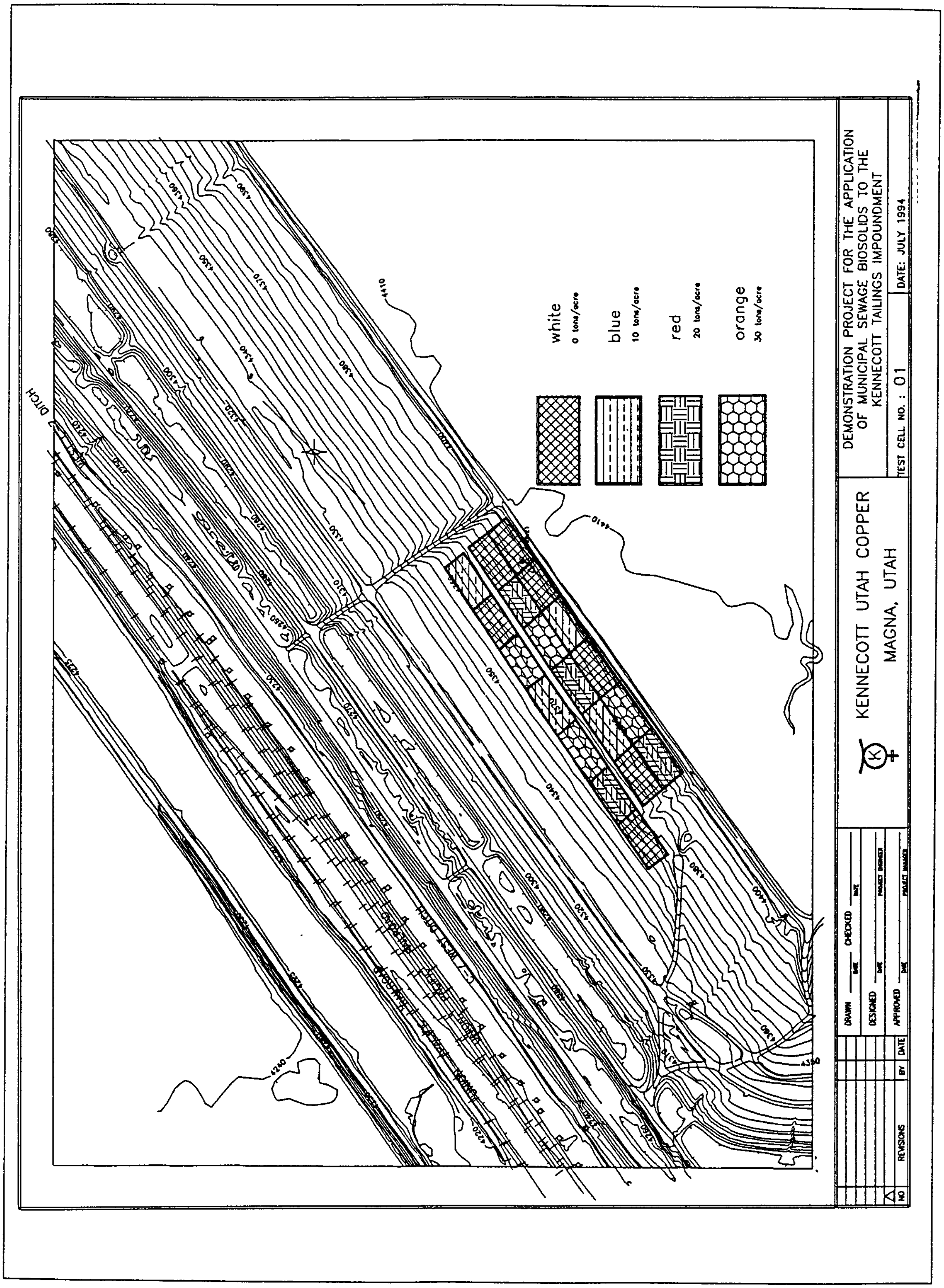


Figure 2- Test Site No. 1, Biosolids Application Rates

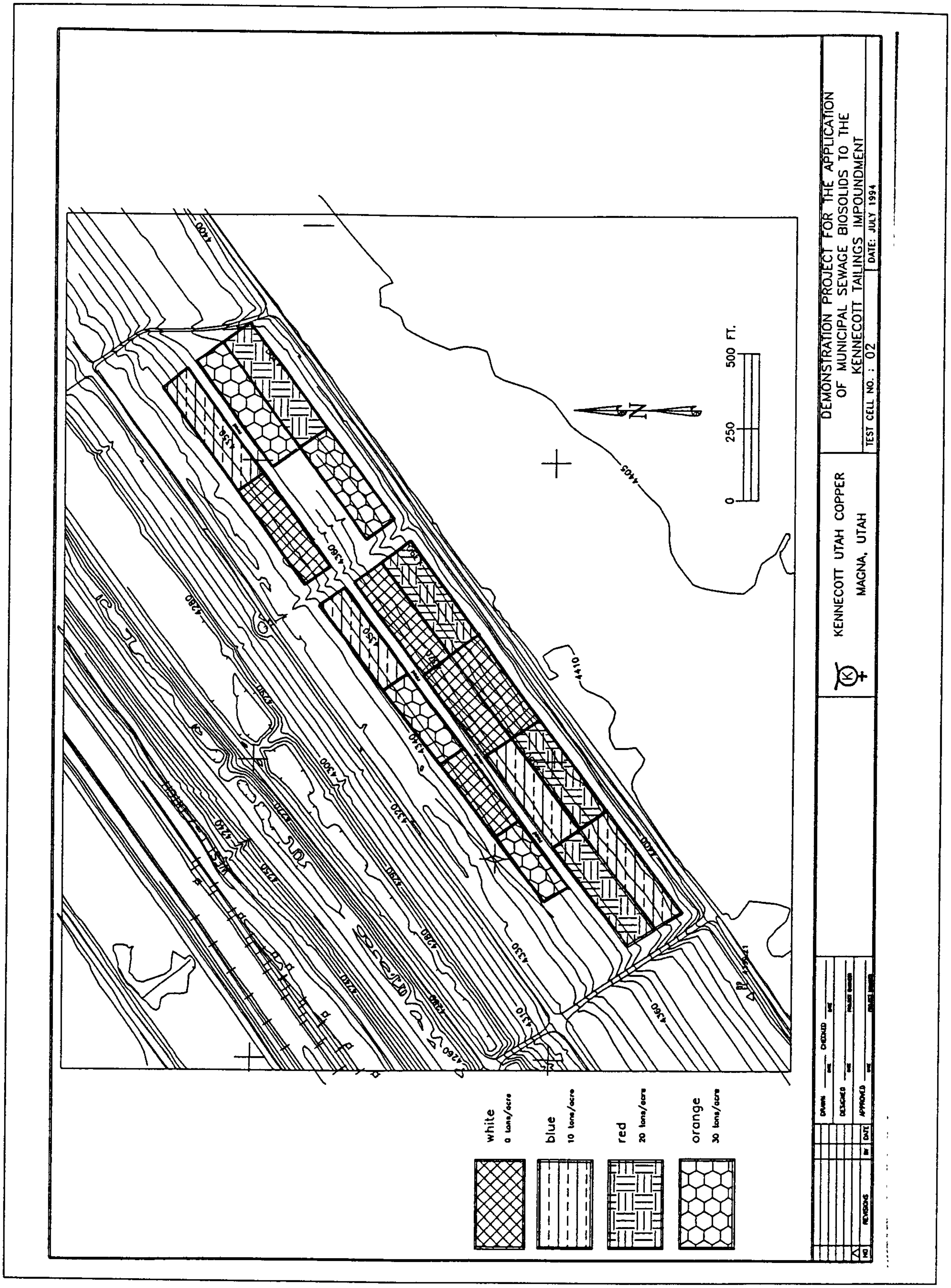


Figure 3 - Test Site No. 2, Biosolids Application Rates

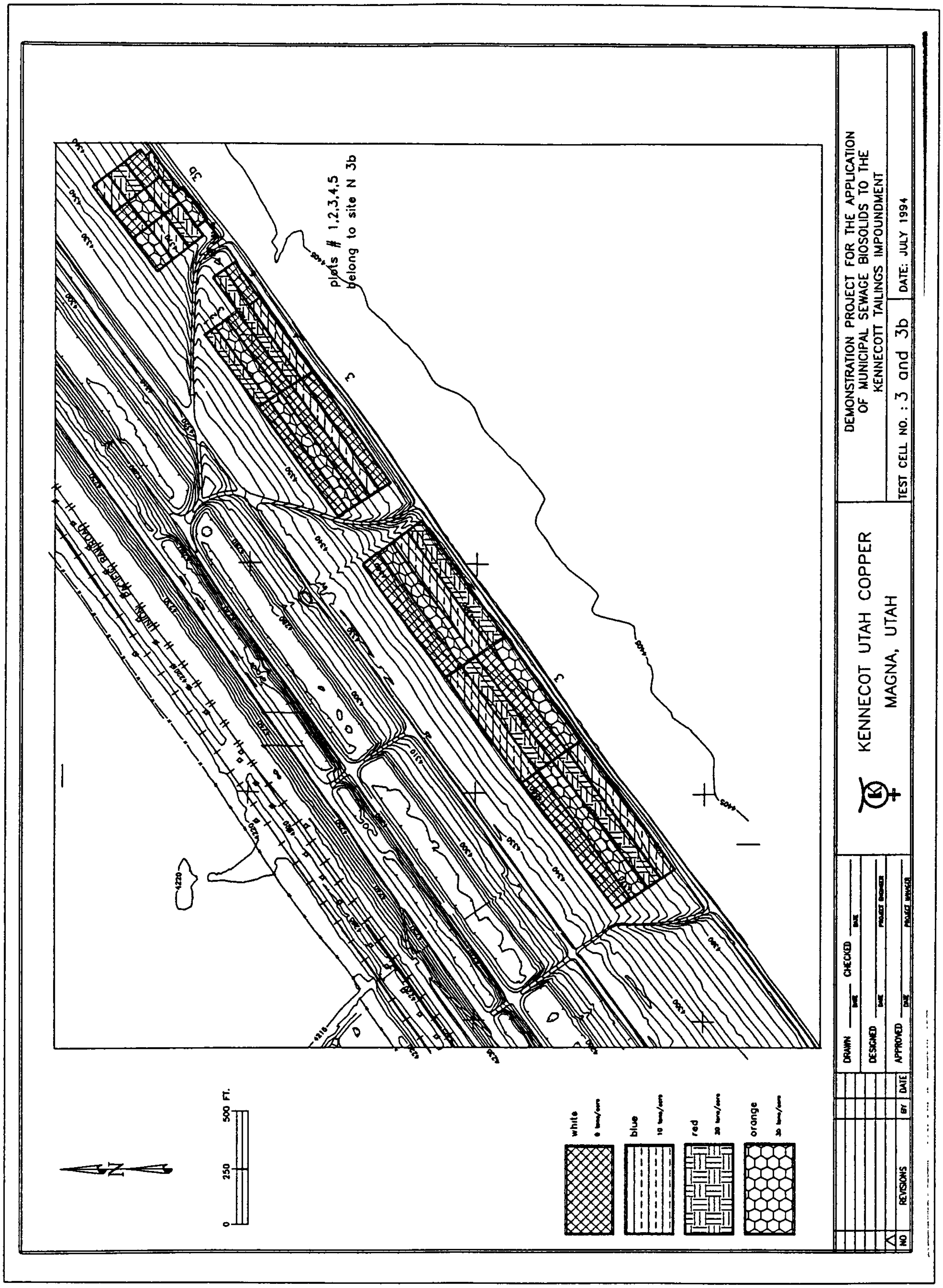


Figure 4- Test Sites No. 3 and 3b, Biosolids Application Rates

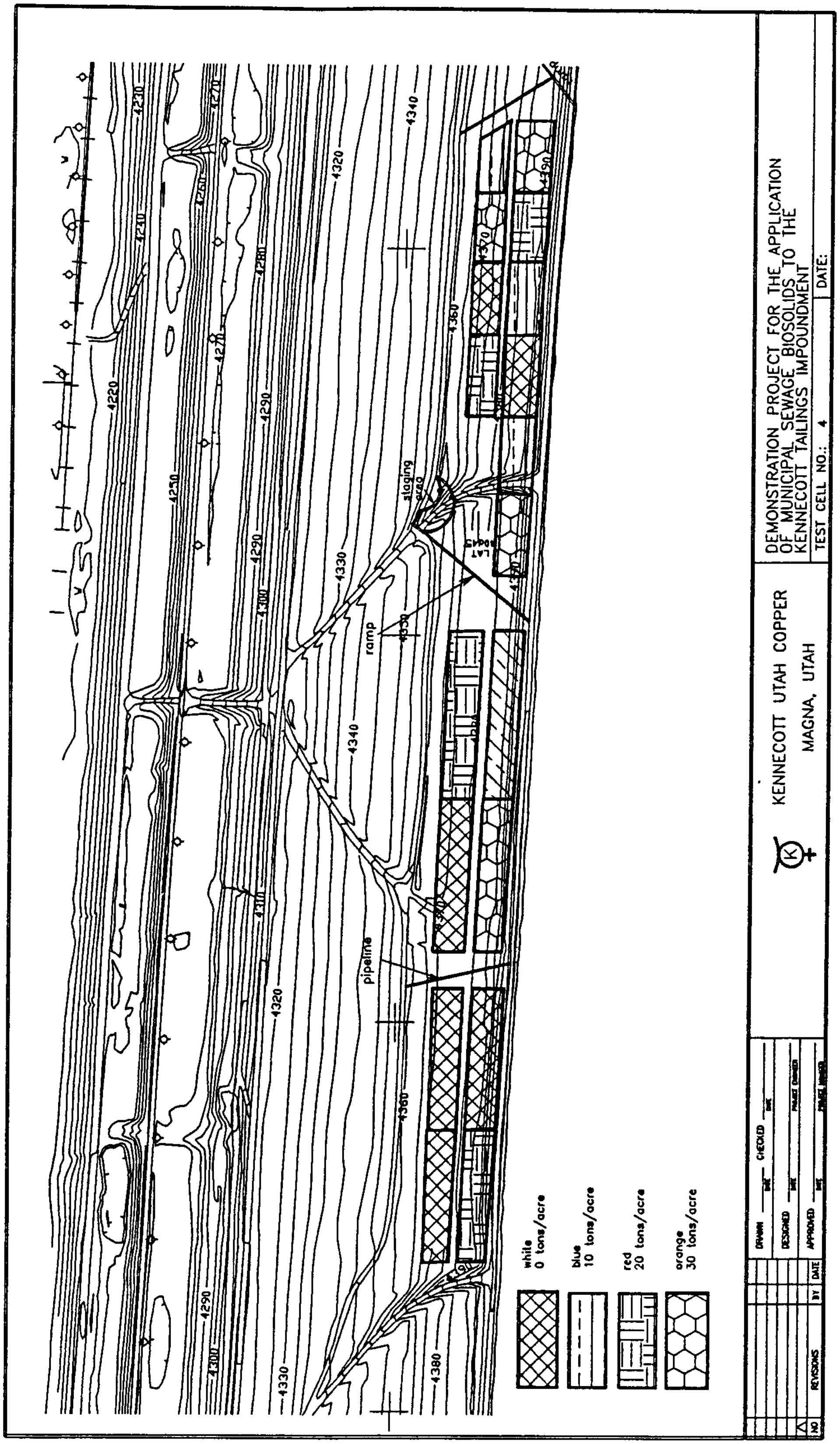


Figure 5 - Tests Site No. 4, Biosolids Application Rates

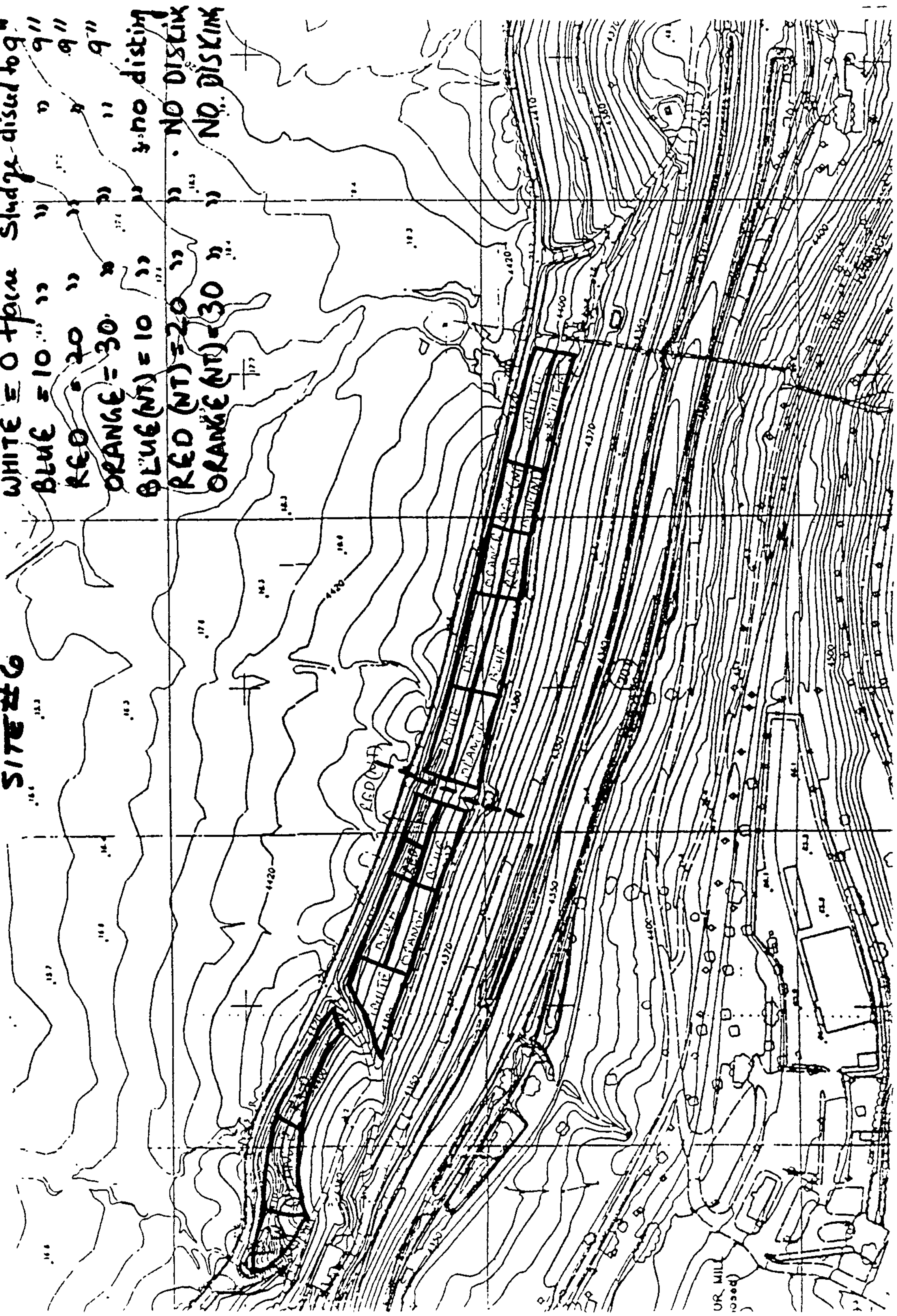


Figure 6 - Test Site No. 6, CVWRF Biosolids (South-Facing Slope)

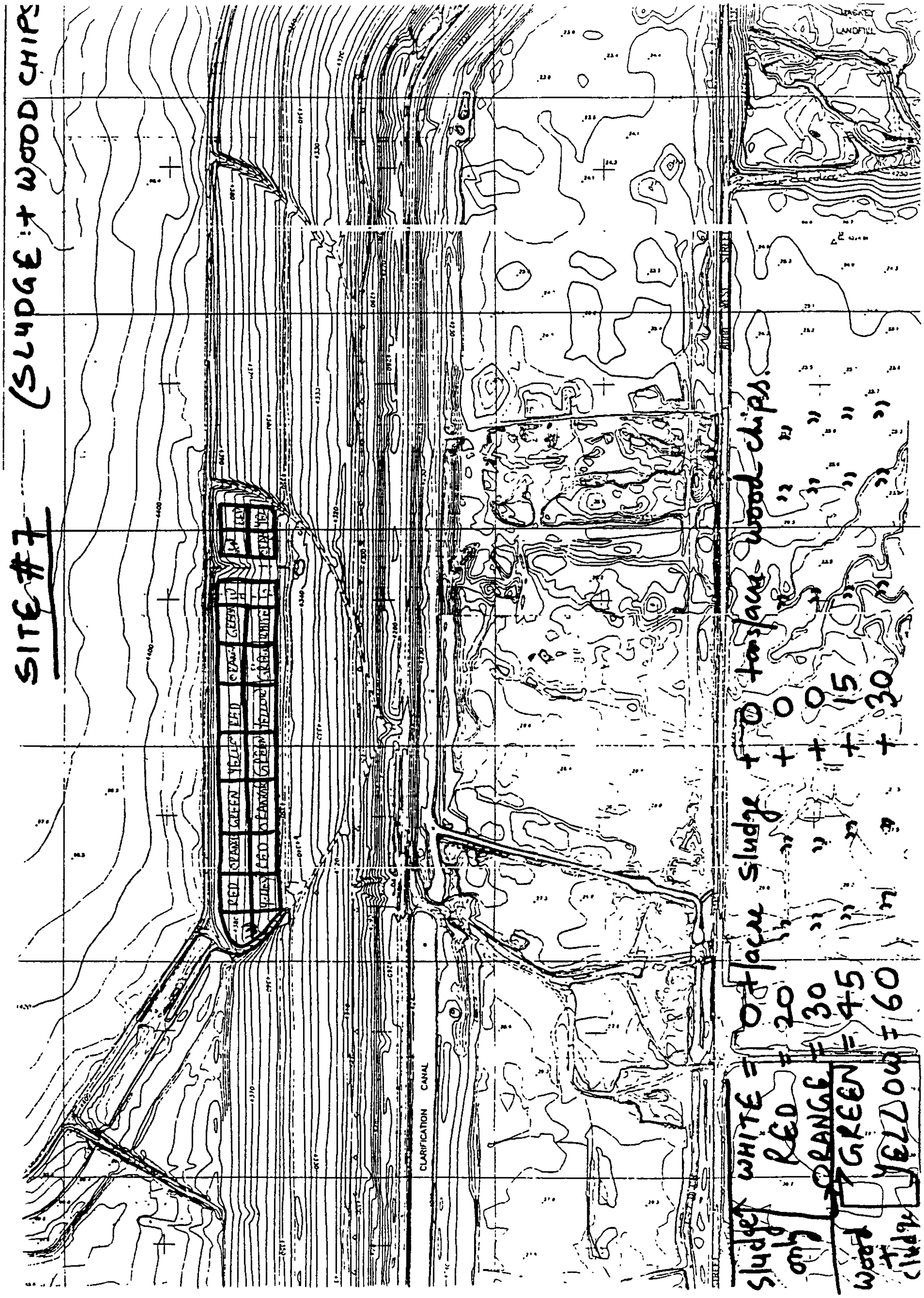


Figure 7- Test Site No. 7, CVWRF Biosolids plus Wood Residues (East-Facing Slope)

Four sites (Sites No. 1, 2, 3 and 3B) were established on the northwestern slope of the impoundment, facing the Great Salt Lake. Site No. 4 was north facing, site No. 6 was south-facing, and site No. 7 was east-facing (Fig. 1). The slopes of the test sites vary from a minimum of 20 to 1 to a maximum of 7 to 1. The location map and the site maps are attached as Figs. 1 through 7. Each site was divided into approximately 16 plots of 0.5 to one acre each, giving a total of 114 plots for the seven sites.

The following seven test sites, chosen for slope aspect and weather conditions, are as follows:

1. Test Site No. 1 : Northwest-facing, 8 to 1 slope, 19 acres. This test site is subjected to severe drying conditions from persistent winds. This test site is also subject to lower pH conditions (range: 2.6 to 7.7). Slaked lime has been applied at a rate of 6 tons/acre prior to the application of biosolids. This site was divided into 19 one-acre plots (Fig. 2).

2. Test Site No. 2: Northwest-facing, 8 to 1 slope, 16 acres. This test site is also subjected to severe drying conditions from persistent winds. This test site is also subject to variable pH conditions (range: 3.1 to 7.8) and would be compared to test sites No. 1 and 3. Biosolids only have been applied to this test site. Trees are also present on this test site. This site was divided into 16 one-acre plots (Fig. 3).

3. Test Site No. 3: Northwest-facing, 8 to 1 slope, 18 acres. This test site is also subjected to severe drying conditions from persistent winds and localized low pH conditions (range: 2.8 to 7.9). Wood chips have been applied at the rate of 30 tons/acre prior to the application of biosolids. This site was divided into 16 one-acre plots (Fig. 4).

4. Test Site No. 3B: Northwest-facing, 8 to 1 slope, 11 acres. This test site is adjacent to test site No. 3. This site was divided into 16 plots of approximately one-half to three-quarter acre each. Aerobically digested (Class B) biosolids from the Magna wastewater treatment plant have been applied (Fig. 4).

5. Test Site No. 4: North-facing, 8 to 1 slope, approximately 18 acres. Biosolids only have been applied to this site. This site was divided into 18 plots of approximately one acre each (Fig. 5).

6. Test Site No. 6: South-facing, 8 to 1 slope, approximately 16 acres. Biosolids and $CaCO_3$ have been applied to this site (Fig. 6).

7. Test Site No. 7: East-facing, 8 to 1 slope, approximately 16 acres. Four test plots received biosolids only, four sites received biosolids plus 15 tons/acre of wood residues, and four test plots received biosolids plus 30 tons per acre of wood residues (Fig. 7).

8.2 Application of amendments and seed-bed preparation

Coarse sand-sized $CaCO_3$ particles (as a limestone reject from the lime slaker at the KUCC wastewater treatment plant) were applied to Sites No. 1 and 6 and wood residues were applied to Sites No. 3 and 7. All the sites received four levels of biosolids application (0, 10, 20, and, 30 t/acre, on dry weight basis from CVWRF, except Site 3B and selected plots of Site 7. Site 3B received aerobically-treated biosolids from the Magna wastewater plant. Site No. 7 received two additional application rates of 45 dry tons/acre and 60 dry tons/acre. Biosolids were applied to Sites 1, 2, 3, 3B and 4 by CVWRF personnel using a spreading machine called a "slinger." A manure spreader was used to apply biosolids to sites No. 3B, 6 and 7. The biosolids were then plowed in by an 18-inch disk. Each level of application was replicated at least four times. Plowing in the biosolids, $CaCO_3$ and wood residues helped in the preparation of a suitable seedbed. Besides breaking surface crusting that may have occurred because of the texture of the tailings, it mixed the top 6 inches of tailings with the underlying 6 inches of tailings. The plowing was performed on the contour and the ground was left in a roughened condition. Doing so left many microsites for seed and moisture accumulation.

8.3 Seeding

Sites 1, 2, 3, 3B and 4 were seeded along the contour in the spring of 1995 with a mixture of perennials and legumes (Table 2) using a drill seeder. Sites 6 and 7 were seeded in the spring of 1996. The factors contributing to the diverse array of plants chosen are the climate of the area; physical and chemical properties of spoil materials like texture, pH, salinity, and availability of essential nutrients; suitability of various species based on reproduction, growth rate, colonization behavior, and nitrogen fixing abilities; responses to management alternatives such as irrigation and surface amendments; and performance of a species in previous reclamation efforts at the tailings (Rokich, P. Personal Communication, 1995). Winter rye was used as a cover crop.

Table 2 - Seed Mix

Common Name	Scientific Name	PLS (lb./acre)
Stabilization Cover Crop:		
Winter Rye	Secale cereale	30
Perennial Mix:		
Yellow Sweetclover	Mililotus officinalis	3
Tall wheatgrass	Agropyron elongatum	3
Sheep fescue	Festuca ovina	3
Alfalfa (Ranger)	Medicago sativa	5
Winter rye	Secale cereale	10

9 Scope of work

Prior to the initiation of the field work, a work plan, field sampling plan, and safety, health and environmental plans were written for this demonstration project by KUCC and University of Utah personnel. Extensive quality control/quality assurance measures were incorporated into the project to ensure that field and laboratory performance will conform to proper sampling and testing protocols.

9.1 Sampling Runs

The test sites were sampled one time for chemical characteristics and two times for agronomic characteristics in the first year, and annually for years 2, 3, 5, and 10 of the study. Initial soil variability was determined from baseline data collection, which was completed prior to the application of biosolids.

9.2 Tailings Samples

Tailings factors most likely to reduce revegetation success are deficiency of plant available nitrogen and phosphorous; plant toxicities induced by excess spoil/tailings acidity; textural extremes; excess soluble salts; and poor physical structure due to excess salts or siltiness (Brady, 1974). For this reason, to find which tailings properties support growth and which are inhibiting, baseline tailings samples were taken. Baseline monitoring was instituted to assess the pre-reclamation environmental conditions of the area and initial tailings variability. Monitoring included detailed sampling and testing to determine the physical properties and chemical characteristics of the tailings. The tailings were also analyzed after the application of biosolids and amendments.

9.3 Agronomic Testing

Baseline tailings samples from within the top six inches of depth were tested for agronomic properties in the summer of 1994, as given in Table 3. This table summarizes the agronomic test, test procedure number, and comments for each test. The samples were composited according to the biosolids application rate. Thus, each test site provided four composited samples. Each sample was split into two, one of which was held in storage should retesting be required and the other was tested by Utah State University. Post-application agronomic sampling runs were made in December of 1994 and July of 1995.

9.4 Chemical Analyses

Samples for chemical testing were collected to a total depth of five feet from the test plots which received 30 tons/acre of biosolids. Samples were collected from the surface and at depths of 0 (0.5), 1, 3, and 5 feet. Table 4 lists the metals, as required by 40 CFR 503, for which tests were performed. The samples were again split; one split was tested by the Kennecott Environment Laboratory (KEL); the other will be held in storage should repeat analyses be required, and some of split samples were used for QA/QC testing. The metals were extracted from the tailings using extraction method 3050 (SW-846). Table 4 summarizes the chemical test, test number, and detection limits for each test.

Table 3 - Agronomic Test Program

Agronomic Test	Utah State University Method	Detection Limits
pH	Saturated Paste	1.0-14.0 mg/L
SAR	Calculated from Ca, Mg, Na	0.01 mg/L
Kjeldahl Nitrogen	Kjeldahl Nitrogen	0.01 %
N as nitrate	$Ca(OH)_2$ extraction with analysis by chromatropic acid	0.1 mg N/kg
Cation Exchange Capacity	1.0 N NHO_4Ac, pH 7	0.1 mg/100g
Organic Matter Content	Walkely-Black	0.01 %
Soil Texture	Hydrometer	1 %
Phosphorus (available)	Olsen: $NaHCO_3$, pH 8.5	0.1 mg P/kg
Cd, Cr, Cu, Ni, Pb	DTPA	0.2 mg/kg
Fe	DTPA	0.2 mg/kg
Mn	DTPA	0.2 mg/kg
Ca	Saturated Paste/ICP	0.15 mg/L
Na	Saturated Paste/ICP	0.2 mg/L
Mg	Saturated Paste/ICP	0.15 mg/L
K (available)	Olsen Bicarbonate, pH 8.5	5 ppm
Water Holding Capacity	Pressure Plate: 1/3, 15 bar mass water content	1 %

NO3-N extracted by the chromotropic acid method (Sims and Jackson, 1971); P and K extracted by Olsen bicarbonate method (Watanabe and Olsen, 1965); paste extract for Ca, Mg, and Na; Cd, Cu, Fe, Mn, Ni, Pb and Zn extracted by DTPA (Linsday and Norvell, 1978).

Table 4 - Chemical Test Program

Chemical Test	SW-846 Test Number	Detection Limits (mg/L)
pH	Method 61-3*	N/A
organic matter	Method 92-3*	2% precision
arsenic	6020	0.5
cadmium	6020	0.2
chromium	6020	1
copper	6020	1
lead	6020	0.5
mercury	7471	0.01
molybdenum	6020	1
nickel	6020	1
selenium	6020	0.5
zinc	6020	1

*from *Methods of Soil Analysis, Part 2* (Black, 1965).

9.5 Sampling QA/QC

To evaluate the precision and accuracy of the testing program, samples were split and re-tested, one for every ten samples. Standard samples, to be included in the testing program, were prepared previously, and were also tested, one for every 20 samples tested.

9.6 Biomonitoring Sampling

Vegetation enhancement was compared with the control plots for each test site, and its success was determined as a function of measured biomass production, species diversity and percent cover measured by one transect across the plot using the line intercept method (Chambers and Brown, 1983). Within each plot, vegetation was identified by transect and bagged by individual species. Species diversity was calculated directly from the field notes and by sample collection. Biomass sampling and species diversity transects were performed in the summer of 1995. These measurements will again be taken in the summer of 1996 and 1997. For biomass production, plant species was harvested from the test plot, dried and weighed to obtain total above-ground biomass and species-weighted biomass results.

9.6.1 Plant production (Biomass)

Above ground biomass estimates were obtained by hand-clipping five randomly located 1-m diameter circular quadrats from each plot during the summer of 1995. Plants within each quadrat were clipped approximately 1 cm above the tailings surface, bagged, and returned to the laboratory. There they were dried to constant weight in a forced-air oven at 140 °F for 24 hours and weighed to obtain dry weights.

9.6.2 Percent Cover

Plant areal cover was estimated by species for all the plots during the summer of 1995. Areal cover is defined as the proportion of the ground occupied by a perpendicular projection of the aerial parts of individuals of the species under consideration (Greig-Smith, 1964). A line intercept method of plant cover estimation was used (Chambers and Brown, 1983) on all plots. Only live vegetation was counted in cover estimates. A 100-foot tape was stretched roughly parallel to the long axis of each plot along the embankment face. The percent plant cover was estimated, by species, using a 4-inch diameter, 4-foot-long, cross-wire sighting tube placed at one foot intervals along each transect. The amount of the tailings surface covered by rock was also estimated. Thus 100 readings were taken for each plot and averaged. Cover estimates were taken by species.

9.6.3 Species Distribution (Diversity)

Frequency data provide information on how species are distributed within a plant community or, in this case, across the revegetation plots or within individual treatments. The frequency is the percentage of observations taken through the sighting tube in which a given species occurred. Observations included the percent ground cover of each species. The frequencies of the observations were then averaged for each test plot.

9.6.4 Plant Tissue Analysis

Eighty plant tissue samples were collected for metal analyses. Whole-plant above-ground samples were collected for one or more dominant species identified within each plot. The samples were finely ground, labeled and sent to KEL for analysis. The results were used to evaluate the effects of biosolids application rate, plant species type, moisture availability and the concentration of extractable metals in the tailings or the amount of metal uptake by the plants.

9.7 Biosolids Application

For Sites 1, 2, 3, and 4, the biosolids were delivered by CVWRF trucks to the selected staging areas next to the test sites. Approximately 120 wet tons of wet biosolids were delivered per day. From the staging area, a front-end loader loaded the biosolids onto the "slinger" which then spread the biosolids on the plot. The following color scheme was used to paint signboards on the stakes at each corner of each plot, which guided the slinger driver as to the application rate of biosolids for the particular plot. The Magna biosolids and the CVWRF biosolids applied to Sites 3B, 6 and 7 were delivered by and were applied with a manure spreader by a KUCC contractor.

Orange - 30 dry tons/acre
Red - 20 dry tons/acre
Blue - 10 dry tons/acre
White - 0 dry tons/acre (control)
Green - transect and road markers

The biosolids application was completed in November of 1994 for Sites 1, 2, 3, 3B and 4. Application was completed in October 1995 for Sites 6 and 7.

9.8 Instrumentation

Three instrumentation arrays were installed in each of three plots with the application rates of 0 (control) tons/acre, 20 tons/acre and 30 tons/acre in test site No. 2. In each array, the instrumentation consisted of two resin capsules, placed at the end of a probe at depths of two and five feet; two pressure-vacuum lysimeters, placed at depths of two feet and five feet; and three oxygen probes, placed at depths of two, three, and five feet. Readings were taken approximately monthly since January 1995.

10 Results and Discussion

10.1 Tailings and Agronomic Properties

This section discusses the tailings baseline agronomic characteristics and the changes in tailings properties as a result of the different treatments and biosolids application rates.

The pH of the tailings material was close to neutral both before and after addition of the biosolids (Table 5). Analysis of the extractable constituents -that are available for plant uptake- showed the tailings to be initially low in % OM, NO3-N, P, and Cd; moderate in Mg, Na, Fe, Mn, Ni, Pb, Zn; and high in K, Ca and Cu.

After the addition of biosolids, the N, P, Ca and Zn contents of the biosolids-tailings mix were significantly higher than that of the pretreatment tailings. The pH did not change significantly from the baseline value of 6.8 to an average value of 7.1 for the biosolids-tailings mix. The addition of limestone did not significantly influence the pH of test site No. 1. Organic matter was low in all the sites prior to the initiation of the study. It was expected to be low because it takes many years of plant growth on tailings in a semi-arid environment to accumulate organic matter (Segal and Mancinelli, 1987). But with the addition of biosolids, organic matter content increased significantly from 0.23 percent to 0.83 percent. Nutrients such as Cu, Fe, K, Mg, and Mn were adequate for plant growth before and after the application of biosolids. All extractable constituents decreased in the tailings-biosolids mix from December 1994 to June 1995, indicating uptake during plant growth. Both Ca and Mg showed a significant decrease when compared to their baseline and December 1994 values.

Table 5. Agronomic properties of the tailings and tailings-biosolids mix (mean of twenty measurements).

Tailings, Baseline Measurements (mg/kg)														
			Extractable											
pH	%OM	NO3-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
6.8	0.23	0.01	3.8	131	549	204	82	0.10	73	16	5	0.3	0.1	2
Tailings-Biosolids Mix, December 1994 (mg/kg)														
pH	%OM	NO3-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
6.7	0.83*	111*	35*	142	893*	123	81	<0.10	58	16	4	0.3	0.7	4.6*
Tailings-Biosolids Mix, June 1995 (mg/kg)														
pH	%OM	NO3-N	P	K	Ca	Mg	Na	Cd	Cu	Fe	Mn	Ni	Pb	Zn
7.1	0.39	-----	11	120	273*	24*	28	nd	53	15	2	0.1	0.7	4.0*

NO3-N extracted by the chromotropic acid method (Sims and Jackson, 1971); P and K extracted by Olsen bicarbonate method (Watanabe and Olsen, 1965); paste extract for Ca, Mg, and Na; Cd, Cu, Fe, Mn, Ni, Pb and Zn extracted by DTPA (Linsday and Norvell, 1978), nd designates no detection, * designates a statistical difference from the baseline value at α=0.05.

10.2 Heavy Metals (Total Values)

Total metal content (extraction method 3050 (SW-846)) from surficial tailings samples taken in December 1994 and June 1995 showed essentially no significant increase in levels. These samples were taken from the surface(within 6 inches) from all test plots on all test sites. Table 6 lists the mean and standard deviation for each metal.

Cadmium (Cd) (no detection to 0.1 mg/kg), Cr (no detection), Cu (31 - 113 mg/kg), Pb (0.1 - 1.0 mg/kg), Ni (no detection - 0.6 mg/kg), and Zn (1 - 9 mg/kg) all decreased in the December 1994 samples from their baseline means of 0.39, 34.6, 1278, 13.4, 30.7 and 34 mg/kg, respectively. Whereas, arsenic (6.8 - 37.7) showed higher values than the baseline values (14.3

mg/kg) in only three samples, but the mean value of the December 1994 samples was lower than the baseline mean value. Selenium (1 - 4 mg/kg) was comparable to the baseline value (2.5 mg/kg). Molybdenum (83 - 220 mg/kg) was higher in half the cases than the baseline value of 126.8 mg/kg, but the means were still comparable. All mercury values were low, both for the baseline and the December 1994 values. Thus, total heavy metals content measured in both December 1994 did not increase substantially due to biosolids application.

All metals except As, Se and Mo increased in June 1995 from December 1994, but were generally comparable to the baseline values. Arsenic decreased from December 1994 in all observations except for the 20 t/acre plots in site No. 1 (18 mg/kg). Site No. 3 showed the lowest values for arsenic. Molybdenum (88 - 200 mg/kg) was generally at the same level as both the baseline and the December 1994 samples. Cadmium showed higher values than baseline except in the site No. 3 plots, where it was close to the baseline level. Chromium (28 - 41 mg/kg) increased slightly from the baseline level. Copper (879 - 1747 mg/kg) was generally close to the baseline level. Lead (9.6 - 91.2 mg/kg) and Hg (0.01 - 0.25 mg/kg) mostly increased with increasing biosolids application rate. Nickel (26 - 68 mg/kg) increased more in site No. 1 and 3 than in the sites No. 2, 3, and 3B. Zinc (88 - 128 mg/kg) increased with increasing biosolids application rate for all sites, with a significantly higher mean value when compared to the baseline value.

Table 6. Total metal analyses of surface tailings from all plots (mean and standard deviation), Extraction Method 3050 (SW-846), n = 20

Metal	Baseline	December 1994	June 1995
Cadmium	0.39 ± 0.04	less than 0.1	6.0 ±3.5
Chromium	34.6 ± 1.3	no detection	35.6 ± 3.6
Copper	1278 ± 64	63.6 ± 20.1	1254 ± 195
Lead	13.4 ± 1.6	0.6 ± 0.2	14.0 ± 4.3
Nickel	30.7 ± 0.8	0.3 ± 0.2	41.3 ± 13.9
Zinc	34 ± 1.7	3.9 ± 2.0	110.5 ± 12.6
Arsenic	14.3 ± 1.2	9.8 ± 2.5	3.5 ± 4.4
Selenium	2.5 ± 0.1	2.3 ± 0.7	1.9 ± 0.4
Molybdenum	126.8 ± 7.1	133.9 ± 32.3	127.9 ± 37.1
Mercury	0.009 ± 0	less than 0.01	0.021 ± 0.014

10.2.1 Depth effects on total heavy metal content

Samples taken at depth (0.5, 1, 3, and 5 feet) were only from those test plots which received 30 t/acre of biosolids. The differences from the baseline values are graphed in Figures 8 through 10. Please note that the x-axes vary from graph to graph. Inspection of these graphs reveals a small, but generally not a statistically significant, difference between the means of the samples from the baseline means, not only at depth, but also by location; that is, by treatment. Table 7 lists whether or not a statistical significance does exist in multiple comparisons at depth and by treatment. The comparisons are performed for As, Cd, Cr, Hg, Cu, Se, Mo, Zn, Pb, and Ni at depths close to the surface (0.50), 1, 3, and 5 feet. The mean values followed by different capital letters in the columns and by different small letters in the rows of the table indicate a significant difference at an α=0.05 using the Student-Newman-Keuls test of multiple comparisons. For example, for the baseline As values in the first row, comparison by depth indicates no significant difference between the first and second values (both have the letter "a"), while a difference exists between the first, second and the last two values (which have the letter "b").

Further, since the last two values have the same letter ("b"), there is no significant difference when comparing them with each another.

Arsenic was close to its baseline level (Fig. 8). However, arsenic decreased at the 1-, 3-, and 5-foot depths for sites No. 2 and 4. Cadmium and mercury (Fig. 8), and chromium showed no changes at depth. They are close to their original baseline levels.

Copper varied more at the 1-foot and 5-foot depths than at the 0.5-foot and the 3-foot depths (Fig. 9). The change is perhaps due to the variability in the tailings properties as the amount of Cu applied by the biosolids is less than the amount initially present in the tailings. Molybdenum and lead showed no variation by depth or by treatment (Fig. 9).

Table 7. Tailings total As, Cd, Cr, and Hg at depths of 0.5 foot, 1 foot, 3 feet, and 5 feet.

	Sample Depth (feet)				Sample Depth (feet)			
	0.5	1.0	3.0	5.0	0.5	1.0	3.0	5.0
	As ($mg\text{-}kg^{-1}$)				Cd ($mg\text{-}kg^{-1}$)			
Baseline	14.2Aa	15.2Aa	10.5Ab	8.7Ab	0.79Aa	0.48Aa	0.31Aa	0.38Aa
Site #1	15.5Aa	11.9Aa	15.7Aa	11.6Aa	0.20Aa	0.15Aa	0.10Aa	0.30Aa
Site #3	17.3Aa	16.5Aa	9.9Aa	15.6Aa	0.45Aa	0.43Aa	0.30Aa	0.35Aa
Sites #2&4	14.5Aa	11.3Aab	5.0Bab	5.0Ab	0.25Aa	0.41Aa	0.21Aa	0.28Aa
Site #3B	11.1Aa	14.4Aa	8.0Aa	10.0Aa	0.42Aa	0.35Aa	0.40Aa	0.28Aa
	Cr ($mg\text{-}kg^{-1}$)				Hg ($mg\text{-}kg^{-1}$)			
Baseline	28.5Aa	34.1Aa	34.7Aa	35.7Aa	0.013Aa	0.012Aa	0.014Aa	0.010Aa
Site #1	37.2Ba	35.9Aa	39.0Aa	30.4Aa	0.023Aa	0.015Aa	0.015Aa	0.018Aa
Site #3	42.6Ba	34.9Aa	39.7Aa	35.2Aa	0.025Aa	0.018Aa	0.013Aa	0.013Aa
Sites #2&4	43.1Ba	43.2Aa	35.5Aa	35.5Aa	0.020Aa	0.020Aa	0.013Aa	0.011Aa
Site #3B	44.2Ba	41.0Aa	37.1Aa	41.4Aa	0.015Aa	0.010Aa	0.010Aa	0.009Aa

*Means followed by different capital letters within columns and different small letters within rows for each parameter are significantly different, alpha = 0.05 (Student-Newman-Keuls Test). Site #1 = $CaCO_3$ + Biosolids, Site #3 = Wood Chips + Biosolids, Sites #2&4 = Biosolids Only, Site #3B = Magna Biosolids.

Table 7 (continued). Tailings total Cu, Mo, Pb, Se, Zn, and Ni at depths of 0.5 foot, 1 foot, 3 feet, and 5 feet.

	Sample Depth (feet)				Sample Depth (feet)			
	0.5	1.0	3.0	5.0	0.5	1.0	3.0	5.0
	Cu ($mg\text{-}kg^{-1}$)				Se ($mg\text{-}kg^{-1}$)			
Baseline	1542Aa*	1214Aa	1180Aa	963Aa	3.0Aa	2.5Aa	2.1Ab	2.0Ab
Site #1	1190Aa	1854Aa	1551Aa	1795Aa	4.0Aa	2.8Aa	3.5Aa	3.8Aa
Site #3	1304Aa	1364Aa	1242Aa	1349Aa	2.8Aa	3.5Aa	1.5Aa	1.5Aa
Sites #2&4	1079Aa	1294Aab	985Ab	746Aa	2.6Aa	1.9Aa	1.4Aa	1.5Aa
Site #3B	1010Aa	970Aa	1103Aa	1224Aa	2.5Aa	2.5Aa	2.3Aa	2.3Aa
	Mo ($mg\text{-}kg^{-1}$)				Zn ($mg\text{-}kg^{-1}$)			
Baseline	139.5Aa	128.0Aa	90.1Aa	95.1Aa	34.9Aa	35.1Aa	33.5Aa	34.8Aa
Site #1	63.3Aa	82.5Aa	83.8Aa	67.5Aa	35.5Aa	29.8Aa	27.5Aa	41.8Aa
Site #3	112.0Aa	138.3Aa	61.0Aa	67.0Aa	45.0Aa	34.3Aa	47.3Aa	32.0Aa
Sites #2&4	121.5Aa	141.5Aa	122.6Aa	102.9Aa	42.4Aa	32.3Ab	26.8Ab	29.6Ab
Site #3B	108.3Aa	96.0Aa	140.3Aa	81.5Aa	39.0Aa	30.3Aa	37.5Aa	36.8Aa
	Pb ($mg\text{-}kg^{-1}$)				Ni ($mg\text{-}kg^{-1}$)			
Baseline	19.2Aa	15.3Aa	14.7Aa	12.8Aa	31.1Aa	31.5Aa	29.4Aa	30.2Aa
Site #1	11.2Aa	11.5Aa	9.7Aa	9.9Aa	30.8Aa	27.3Aa	30.3Aa	28.5Aa
Site #3	15.5Aa	18.3Aa	19.4Aa	10.5Aa	31.8Aa	28.5Aa	29.3Aa	25.5Aa
Sites #2&4	18.8Aa	18.2Aa	8.7Aa	8.1Aa	31.6Aa	29.4Aa	25.8Aa	26.1Aa
Site #3B	13.3Aa	22.8Aa	18.2Aa	11.7Aa	30.8Aa	28.5Aa	27.0Aa	32.5Aa

*Means followed by different capital letters within columns and different small letters within rows for each parameter are significantly different, alpha = 0.05 (Student-Newman-Keuls Test). Site #1 = $CaCO_3$ + Biosolids, Site #3 = Wood Chips + Biosolids, Sites #2&4 = Biosolids Only, Site #3B = Magna Biosolids.

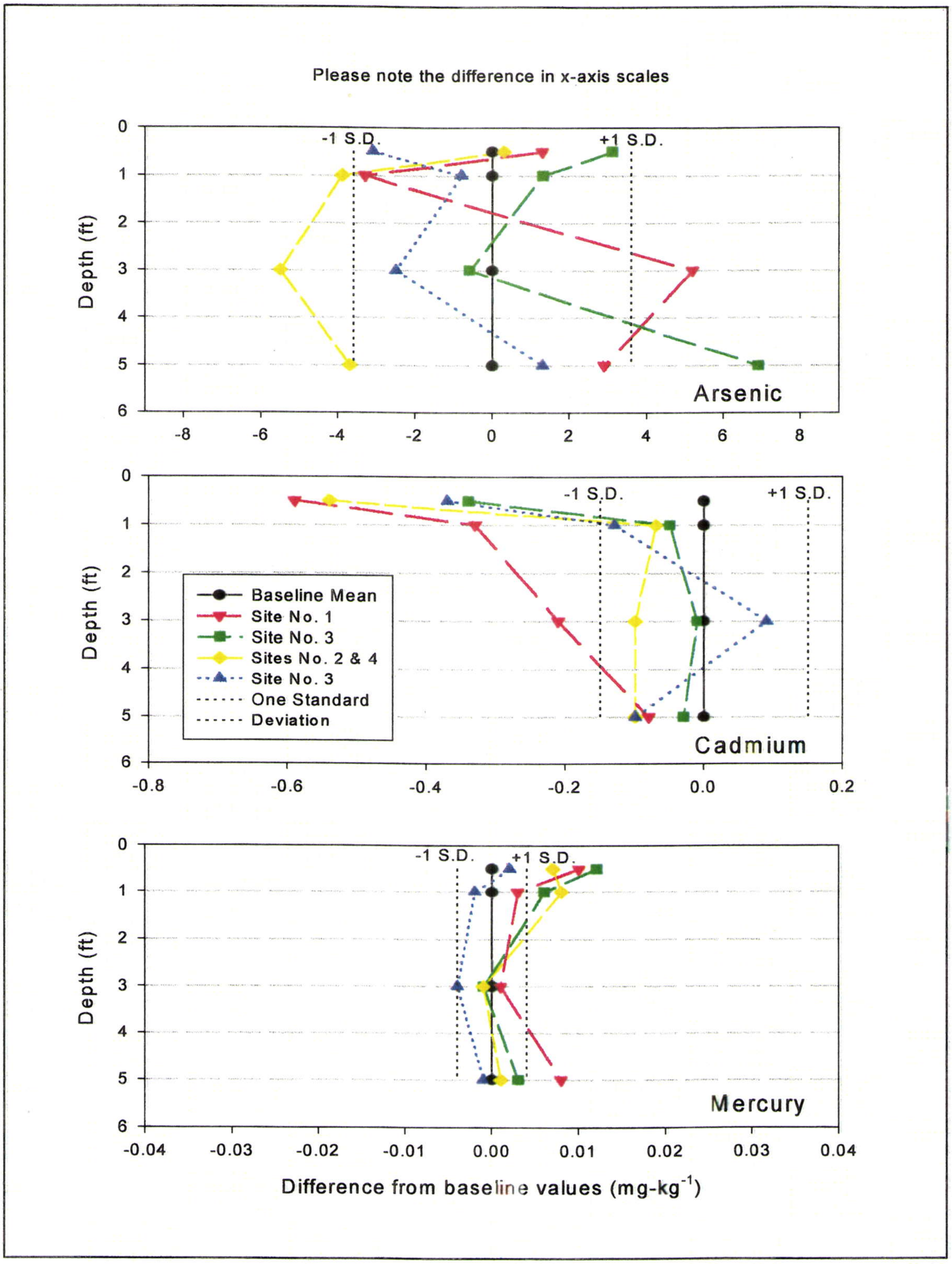


Figure 8 - Depth Effect of Biosolids and Amendment Application (As, Cd, Hg)

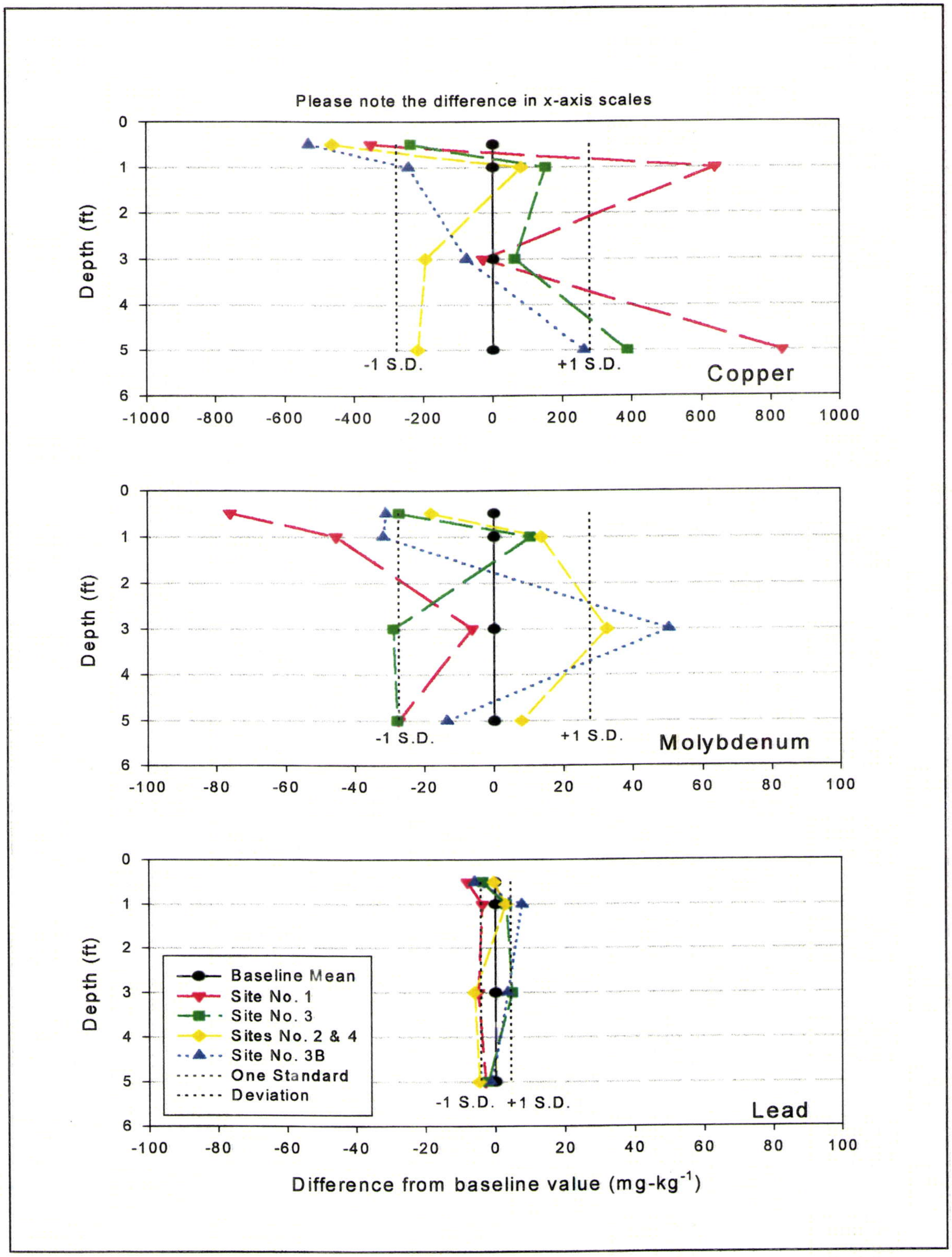


Figure 9 - Depth Effects of Biosolids and Amendment Application (Cu, Mo, and Pb)

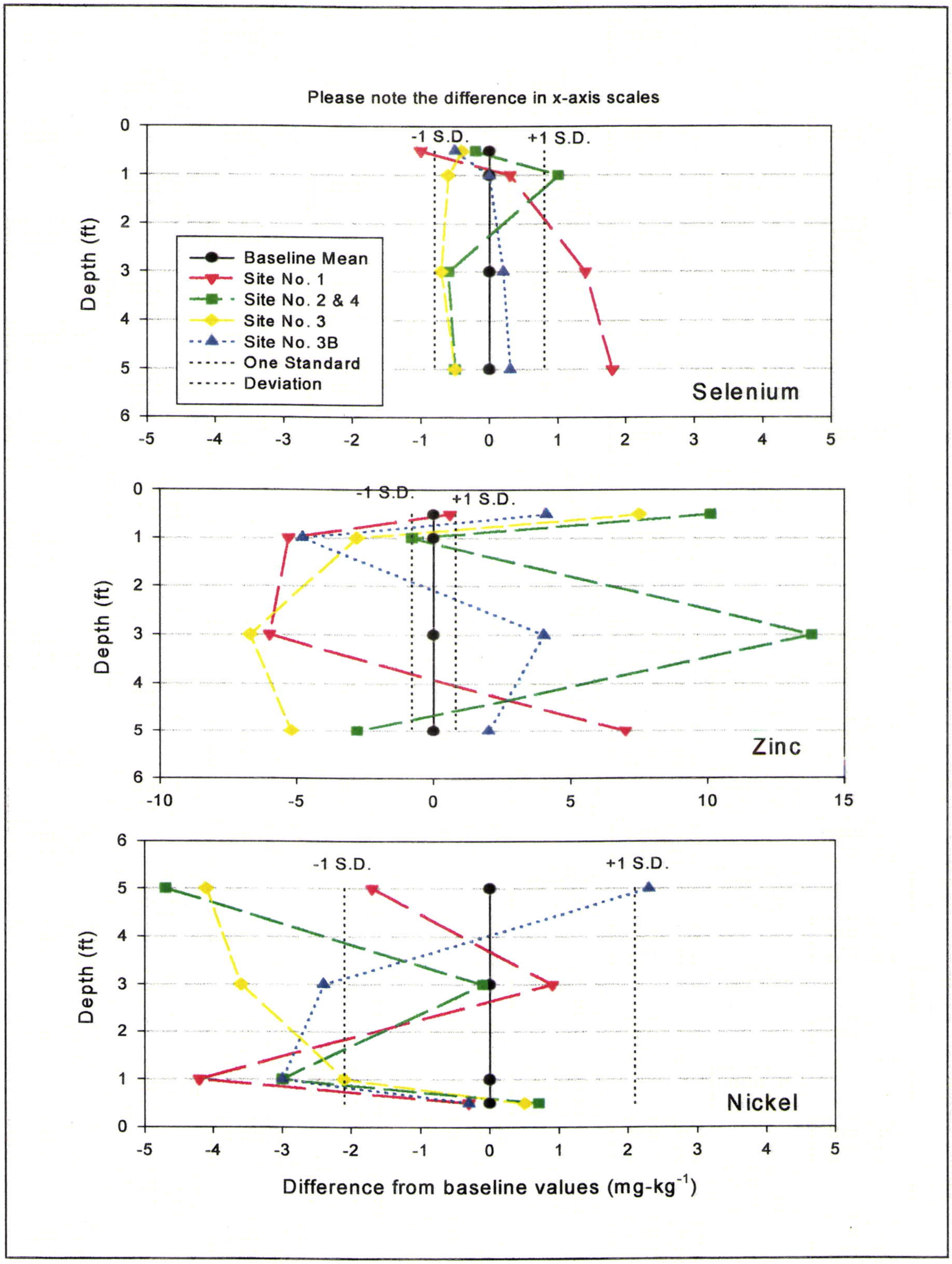


Figure 10 - Depth Effect of Biosolids and Amendment Application (Se, Zn, and Ni)

Selenium was higher than the baseline level for site No. 1 at all depths (Fig. 10). The other values generally are close to the baseline value. With some exceptions, Zn and Ni are close to their baseline levels (Fig. 10).

Generally, the application of the biosolids does not seem to have any significant depth effect. All heavy metals are close to the narrow range of their baseline values. Also, no effect of $CaCO_3$ addition, wood residues application or type of biosolids was readily apparent. It seems that more time will be required to discover the changes in tailings properties with depth as a result of biosolids application, if any.

The tailings samples taken at depth indicate that the downward movement of chemical species, including metals, from biosolids is not a problem. Given these circumstances, a recommendation is made to discontinue solid sampling of tailings for metals at depth. The movement of metals still can be monitored by the resin capsules and the lysimeters, as discussed later in sections 10.3 and 10.4. This recommendation does not apply to the nitrate anion, however. Monitoring of this anion at depth is still warranted.

Examination of tables 6 and 7 shows that no change in variation occurs in the tailings as a result of the addition of biosolids, both by location (or site) nor by depth. This conclusion applies to all of the metals that were analyzed. Based on the analysis of the data collected thus far, any variation which does occur is extremely localized.

10.3 Resin capsule results

Instrument arrays were placed in one control plot, one 20 t/acre plot, and one 30 t/acre plot. The resin capsules captured chemical species from soil water in a similar manner as a plant root does through the selective exchange of ions. The capsules were collected and analyzed monthly throughout 1995.

Figures 11 through 28 present the graphical representations of the discussion that now follows. The most important consideration when evaluating these plots is the trend of the data with time, rather than an occasional peak which may be an outlier. It should also be noted that the control plot appeared to be saturated virtually all of the time, while the other two test plots dried out as the summer progressed. Significant statistical differences between the 2-foot and 5-foot depths are marked with an asterisk next to the application rate on the figures.

Sodium, Mg, and K were higher in the control plot than the other tests plots. Generally, these cations were higher in value at the 5-foot depth than at the 2-foot depth in both the biosolids amended plots. This would be expected as these cations would be taken up by growing vegetation or by evaporative concentration. Values were generally higher in the 30 t/acre plot than in the 20 t/acre plot (Figs. 11 through 13).

Arsenic had higher values in the control plot when compared to the other two test plots and changed little with depth. Values were higher in the 30 t/acre plot than in the 20 t/acre plot (Fig. 14). Iron was higher in the control plot and was close to the same values in other two plots. Values were higher at the 5-foot depth in the 20 t/acre plot but the reverse was true in the 30 t/acre plot (Fig. 15). Cadmium, Cu, Cr, boron (B) and Pb were higher in the control plot and with the exception of some peaks, there were few changes with depth (Figs. 16 through 20). Mercury and Se values were higher in the control plot than the other two plots. Very little change with depth was observed for Se, except for one peak in the 30 t/acre test plot (Figs. 21 and 22). Phosphorous and Ni were close to the baseline levels in all the plots and at all depths (Figs. 23 and 24). Zinc showed a decrease in values after the growing season in the biosolids-amended plots with no apparent leaching of metals. There were few changes in values with increasing biosolids application rate (Fig. 25). Manganese and Mo were higher in the control plot than the other two plots (Figs. 26 and 27).

Nitrate was similar in value at the same depths in both the control and 20 t/acre plots, though it showed an increasing trend with depth and season in the 20 t/acre plot. The values in the 30 t/acre plot were higher at both the 2-foot and 5-foot depths and fluctuated widely. The level of nitrate increased with time, with the values higher at the 2-foot than at the 5-foot depth, as would be expected (Fig. 28).

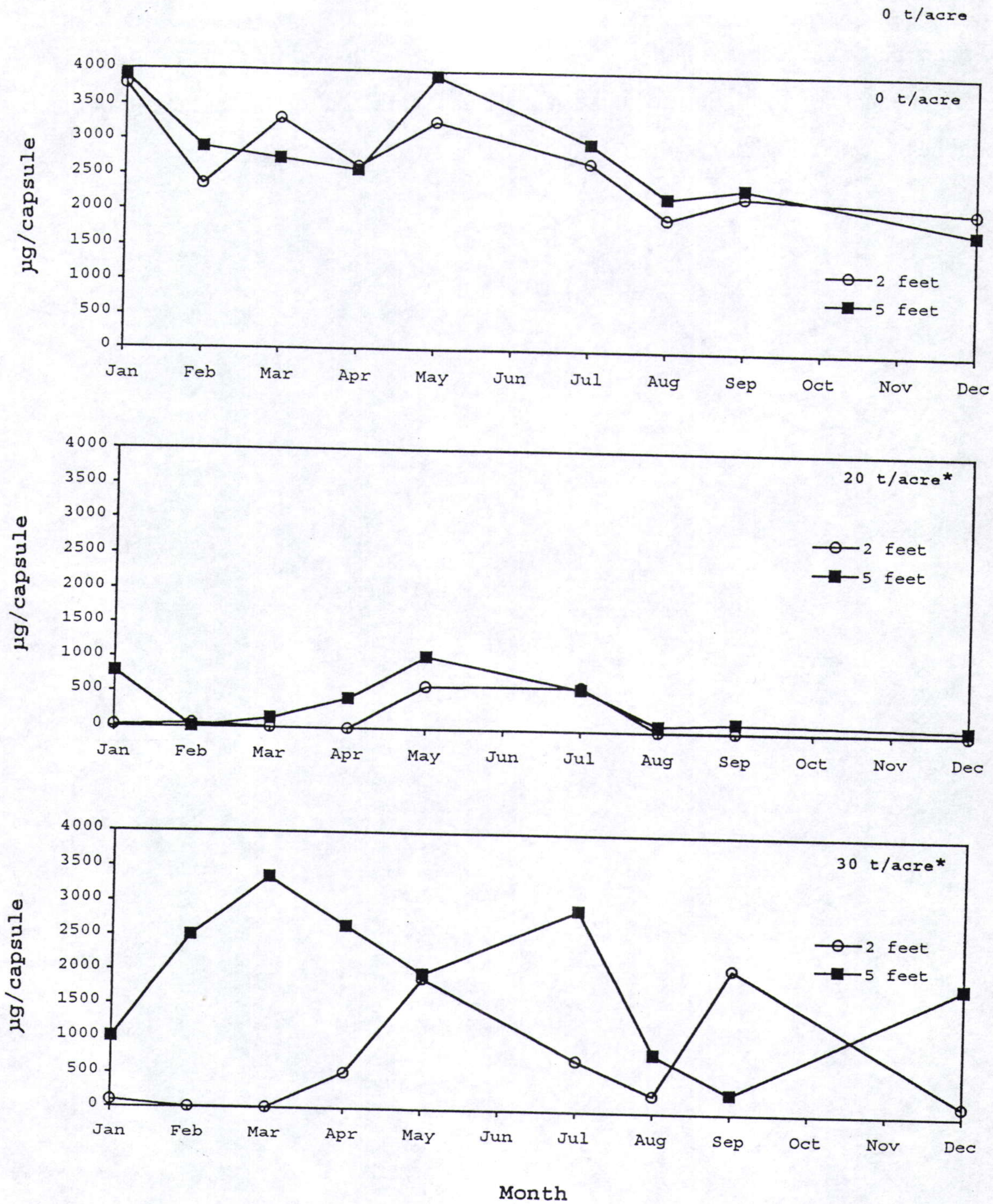


Figure 11. Resin Capsule Results for Sodium

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

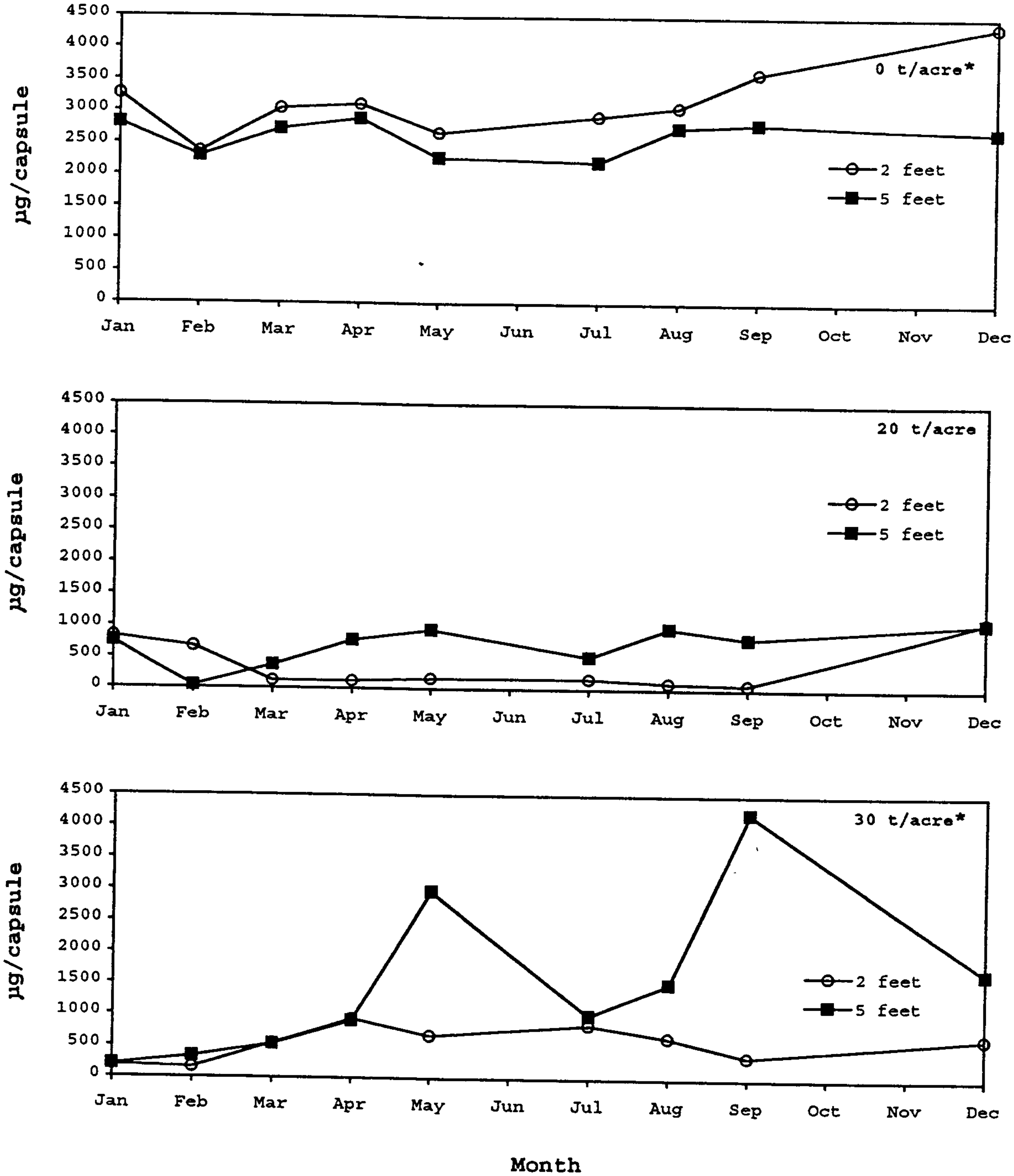


Figure 12. Resin Capsule Results for Magnesium

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

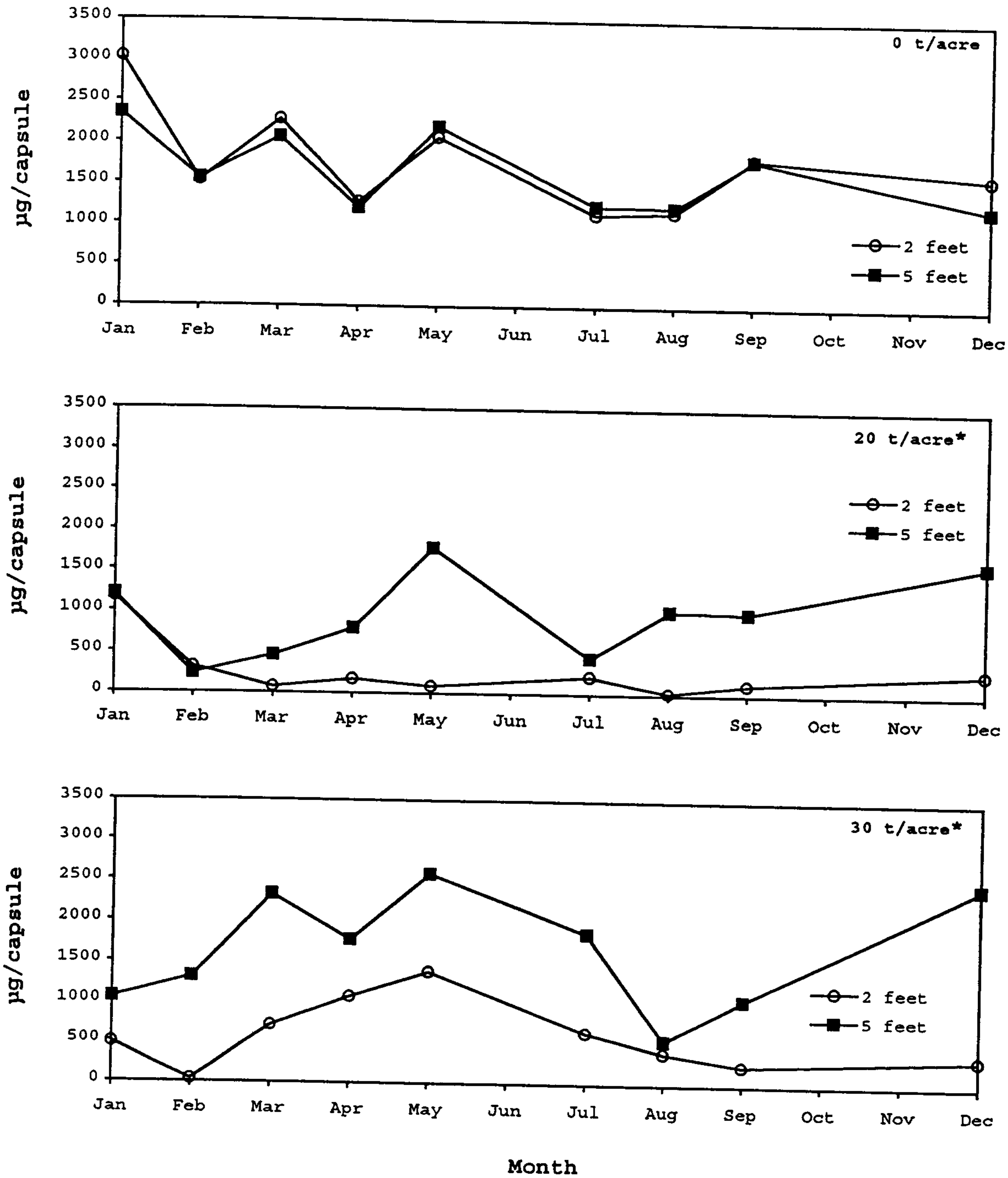


Figure 13. Resin Capsule Results for Potassium

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

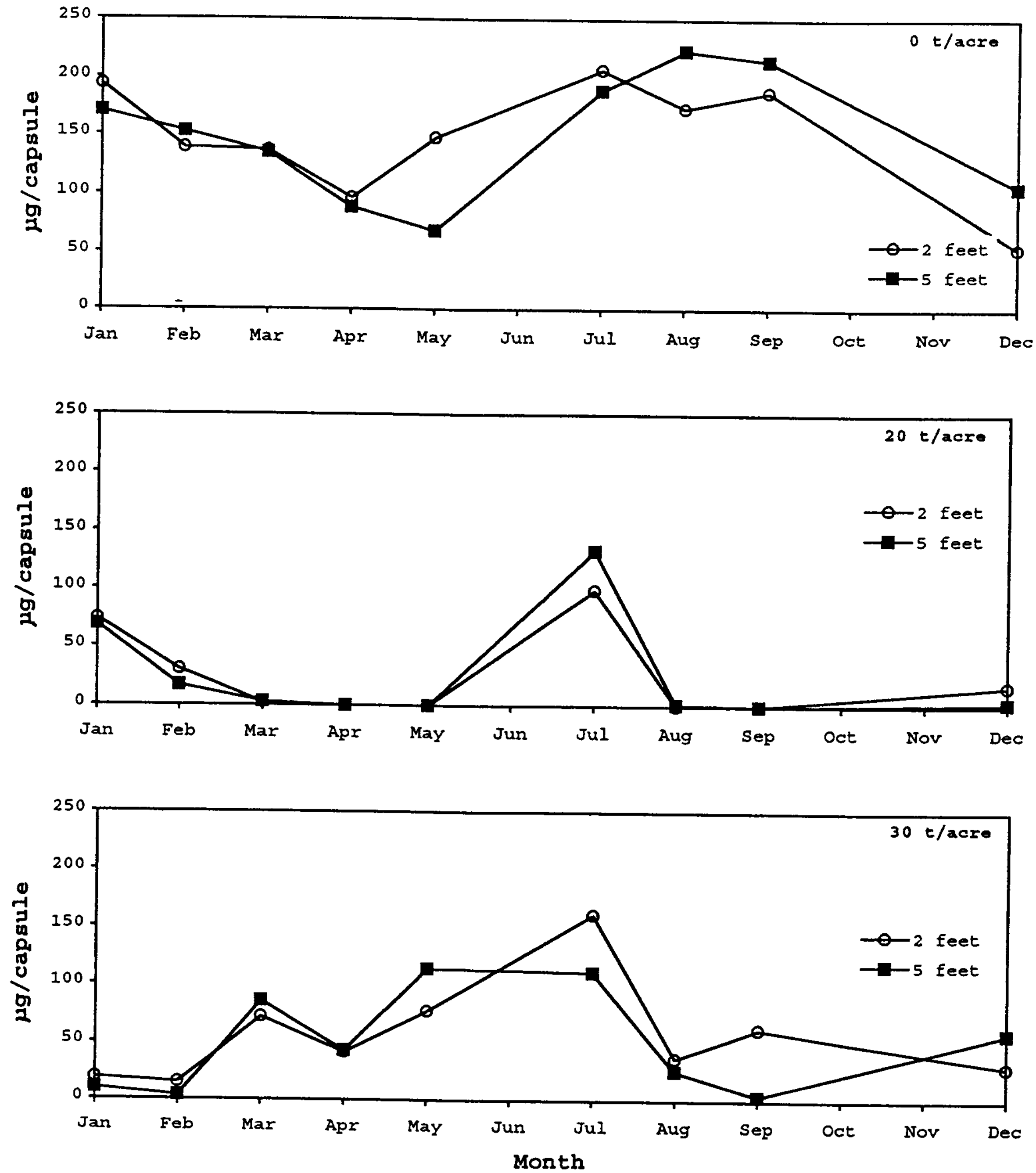


Figure 14. Resin Capsule Results for Arsenic

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

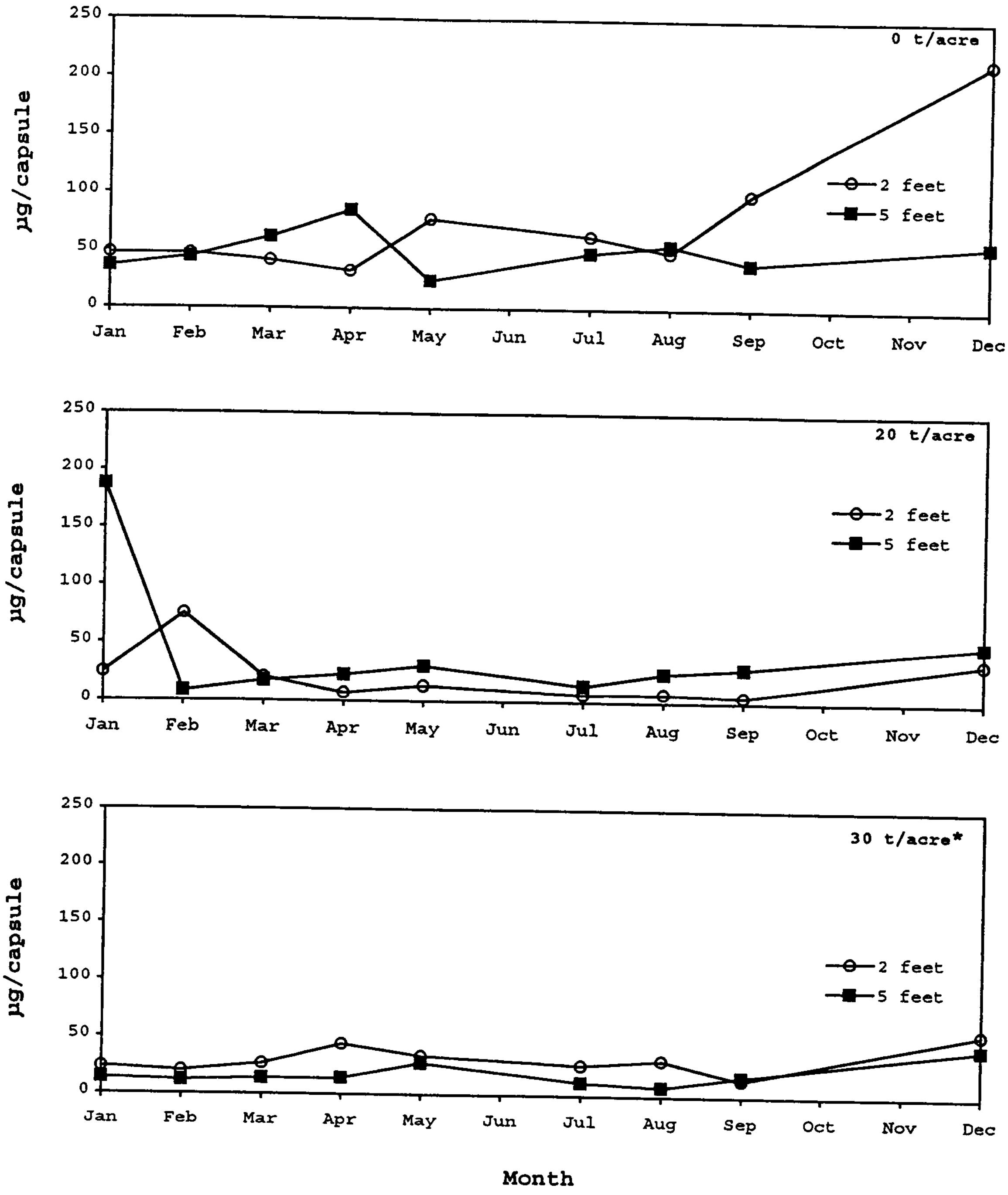


Figure 15. Resin Capsule Results for Iron

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

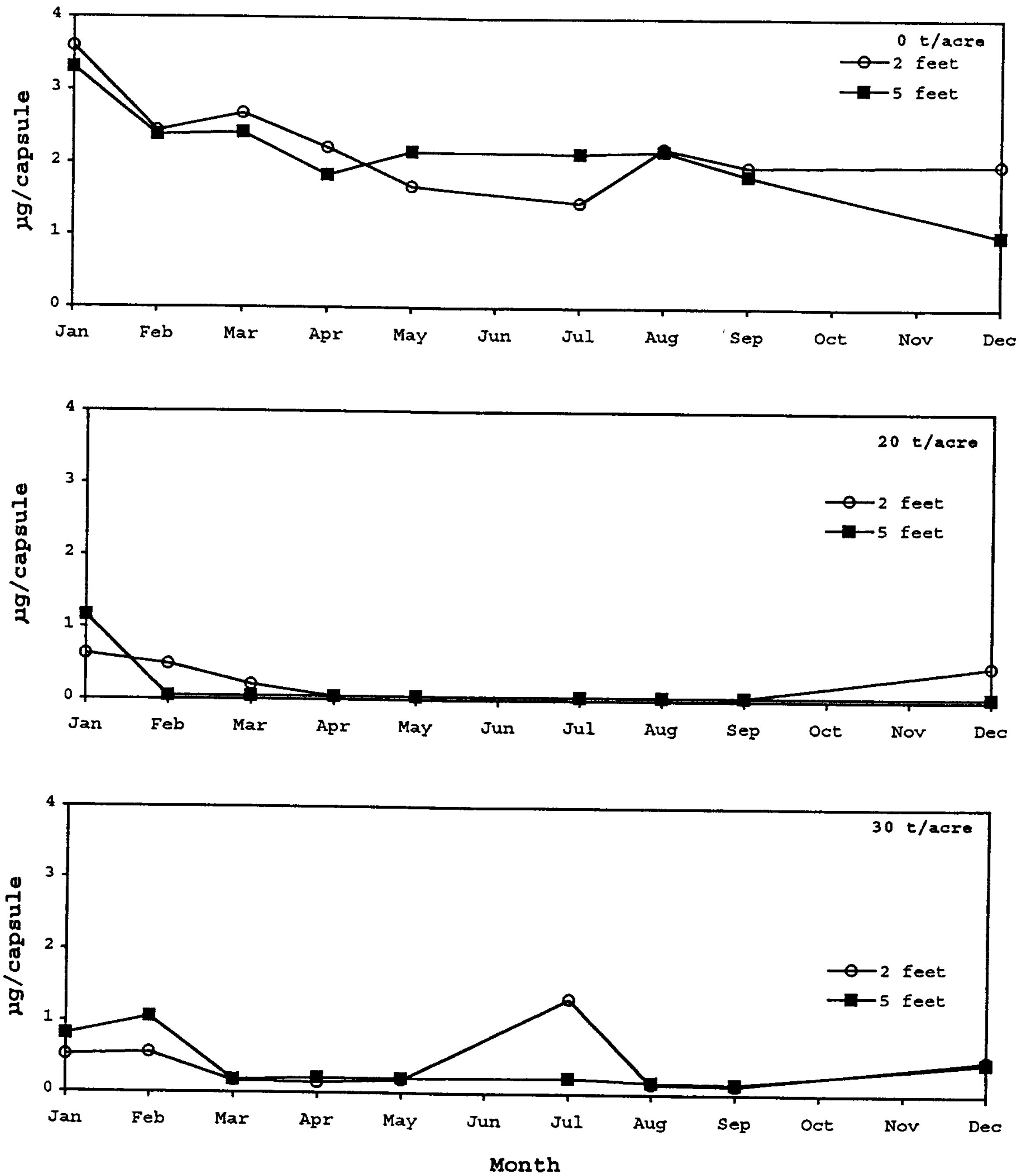


Figure 16. Resin Capsule Results for Cadmiumm

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

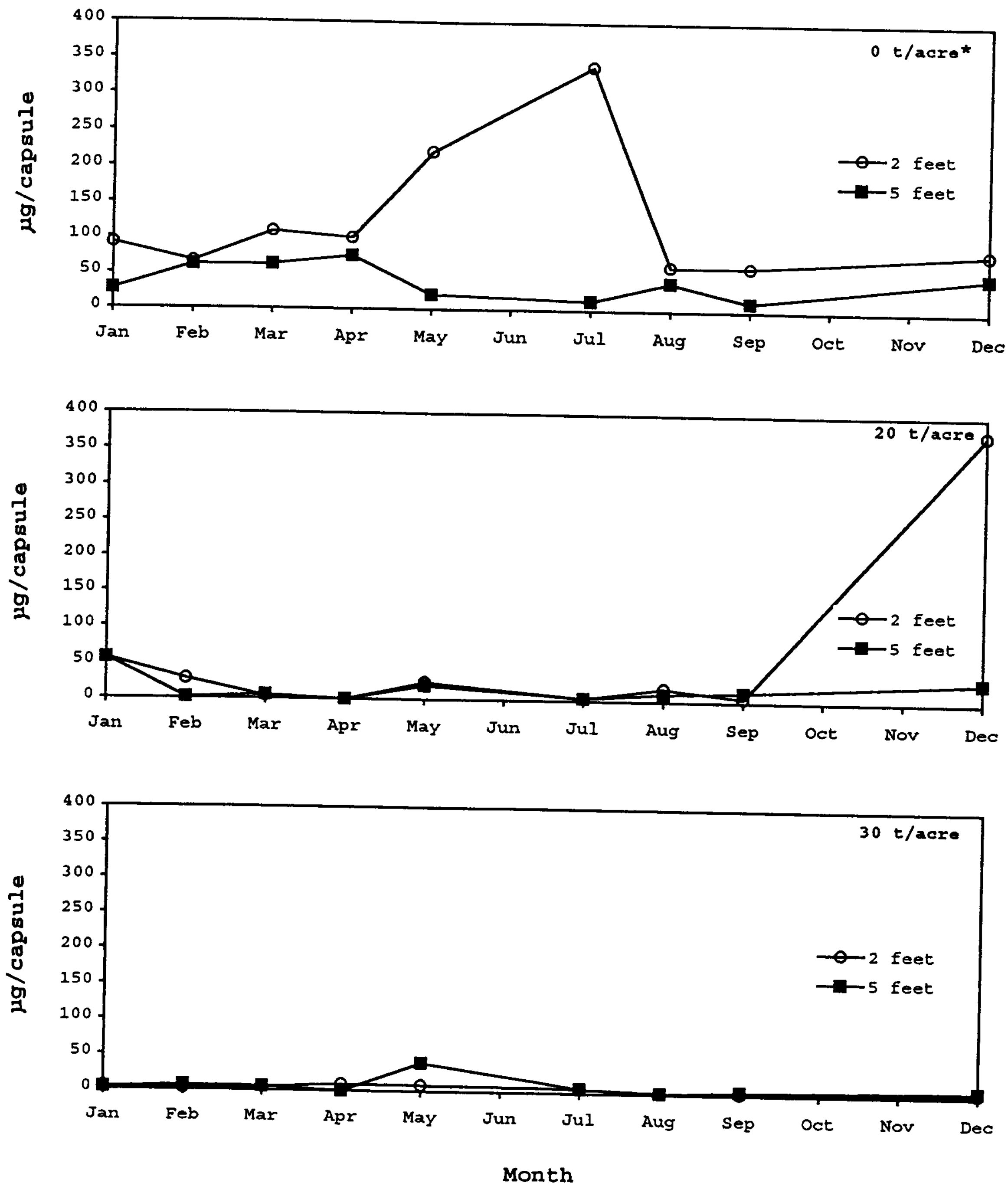


Figure 17. Resin Capsule Results for Copper

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

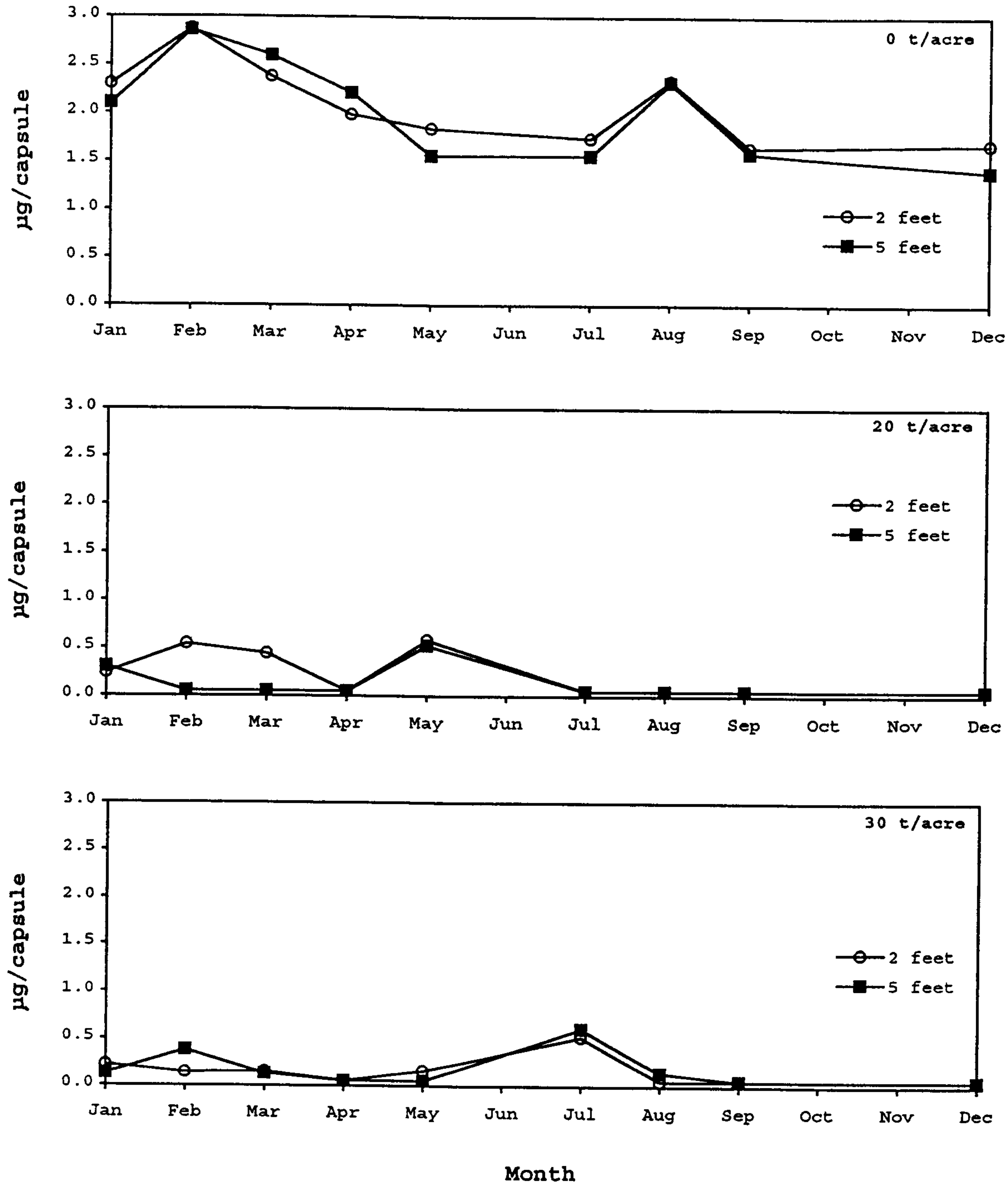


Figure 18. Resin Capsule Results for Chromium

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

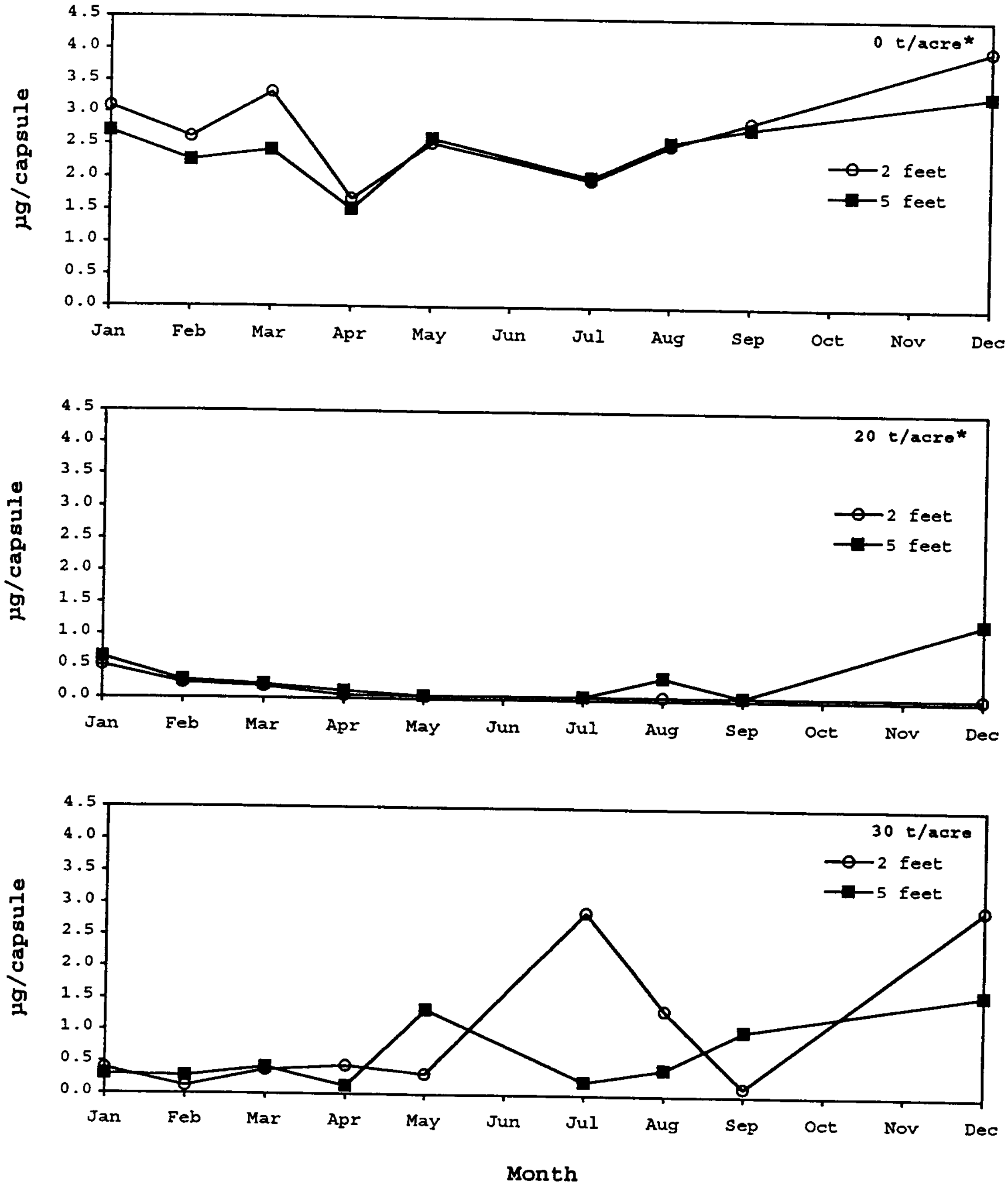


Figure 19. Resin Capsule Results for Boron

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

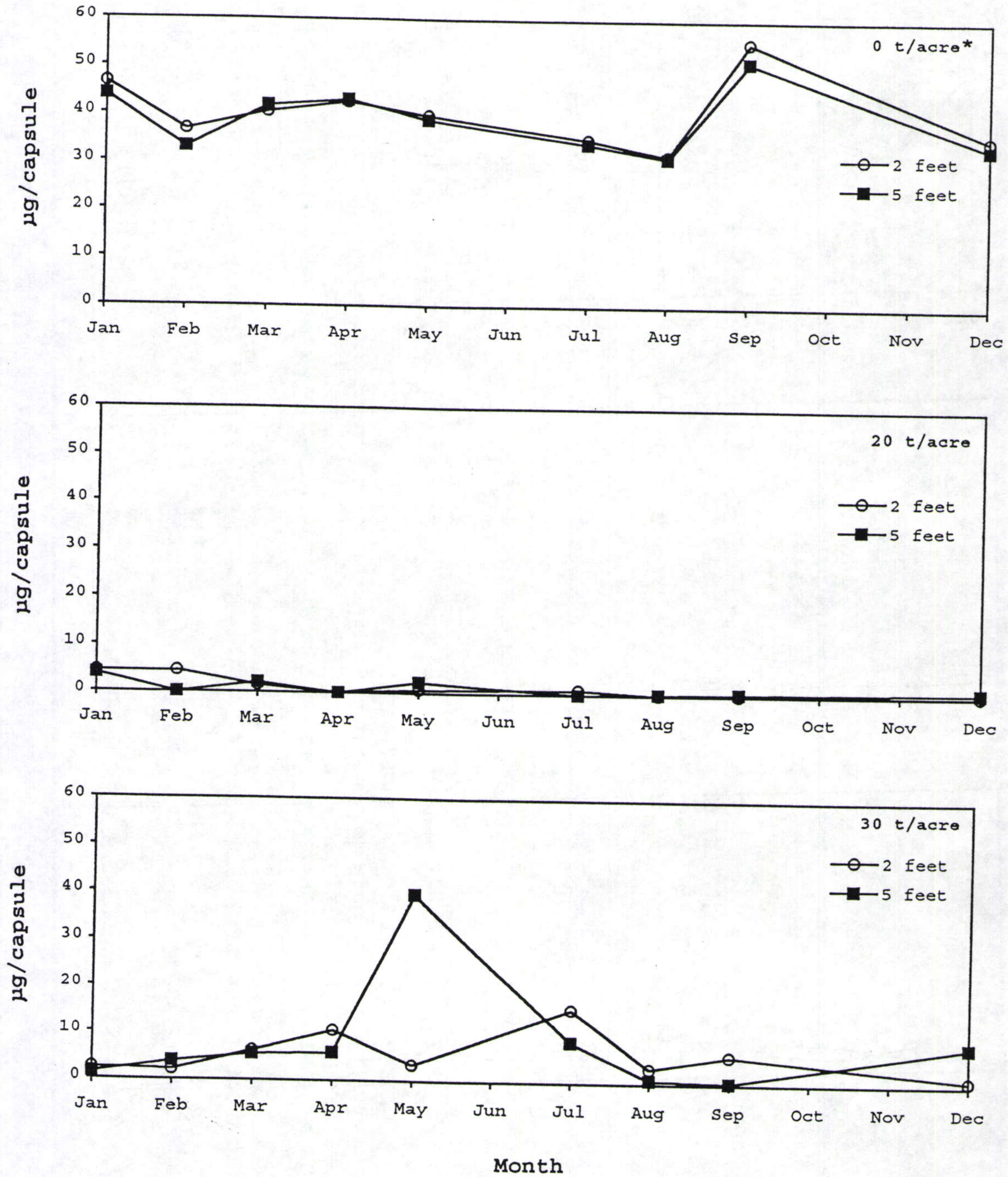


Figure 20. Resin Capsule Results for Lead

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

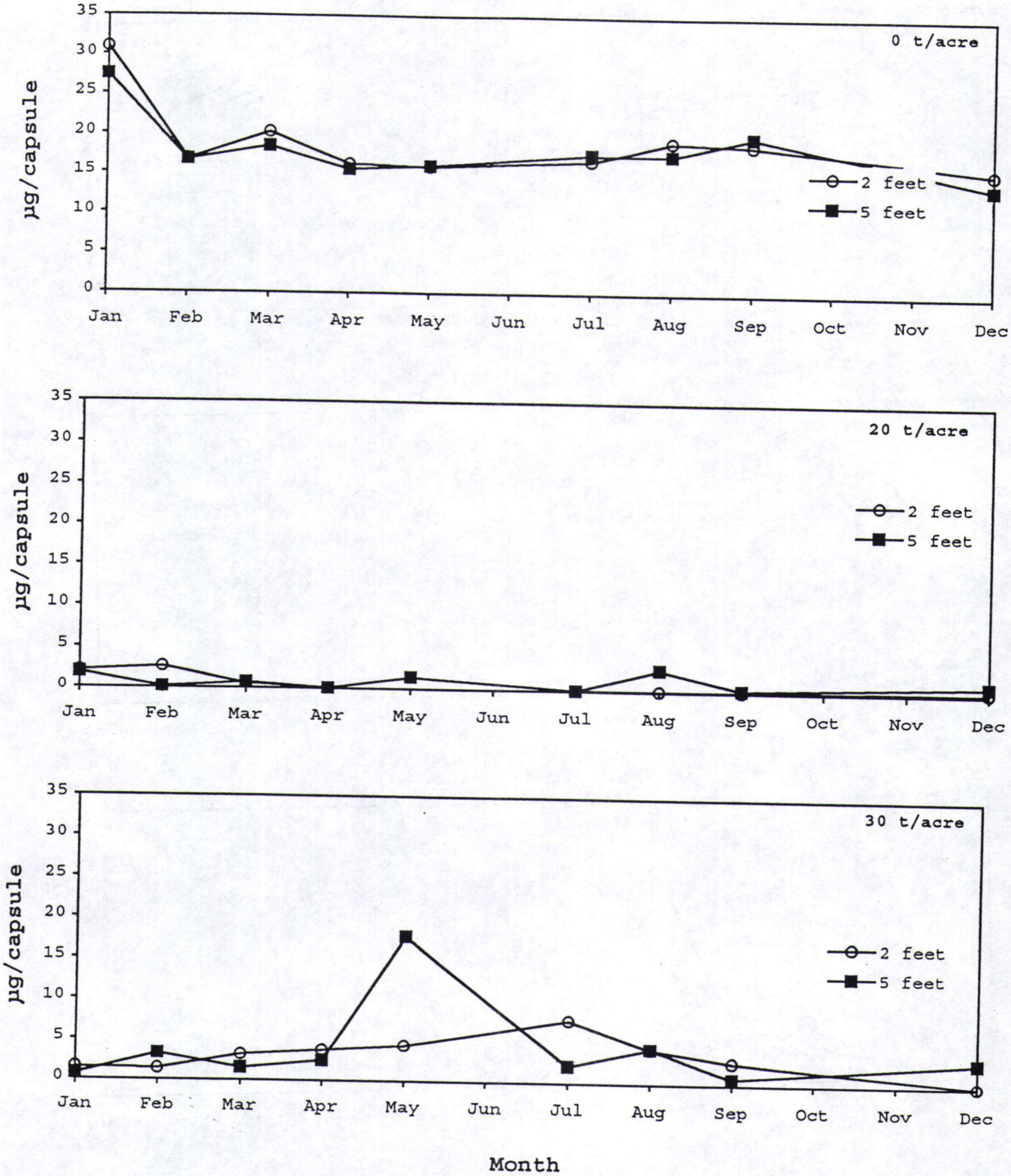


Figure 21. Resin Capsule Results for Mercury

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

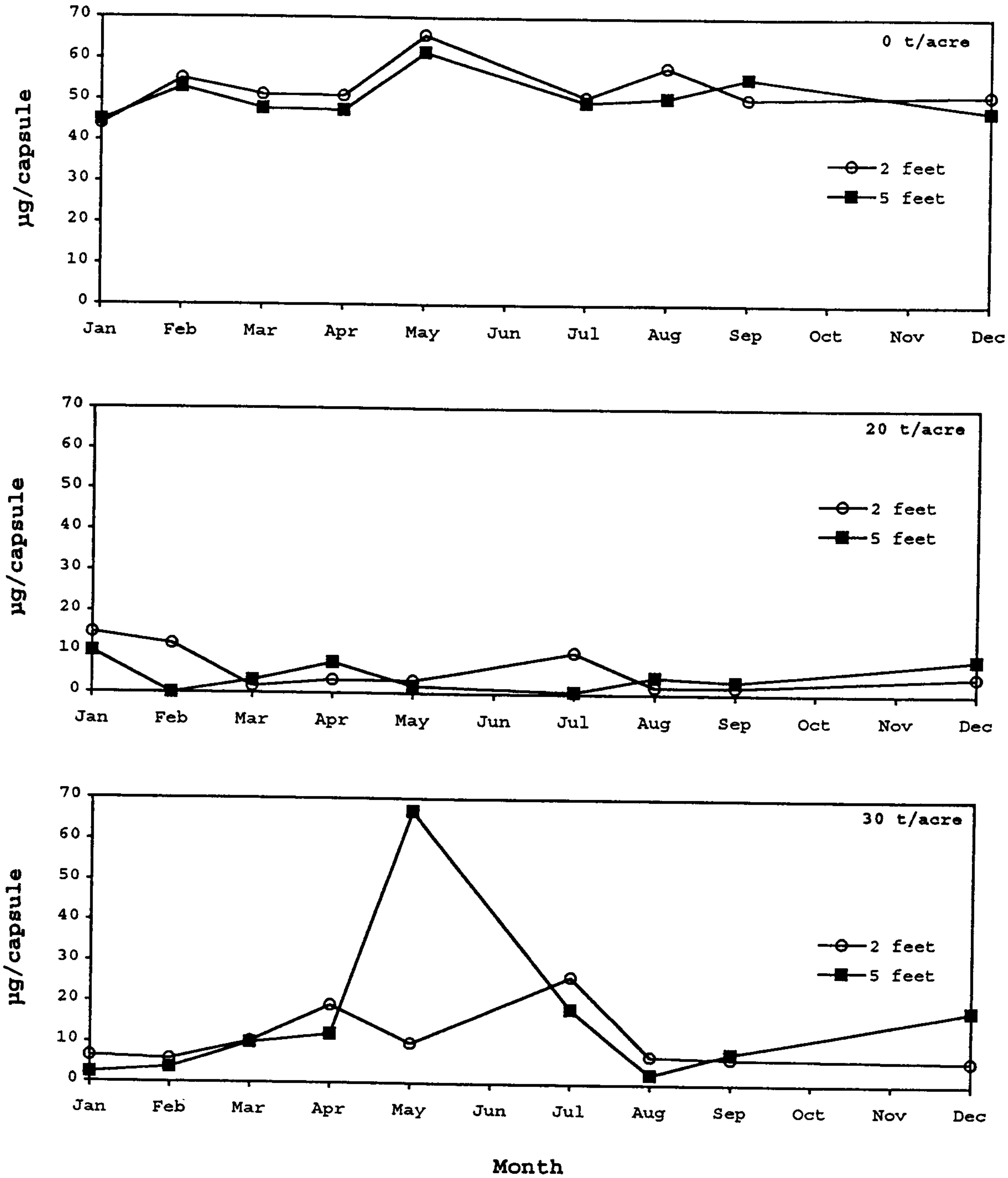


Figure 22. Resin Capsule Results for Selenium

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

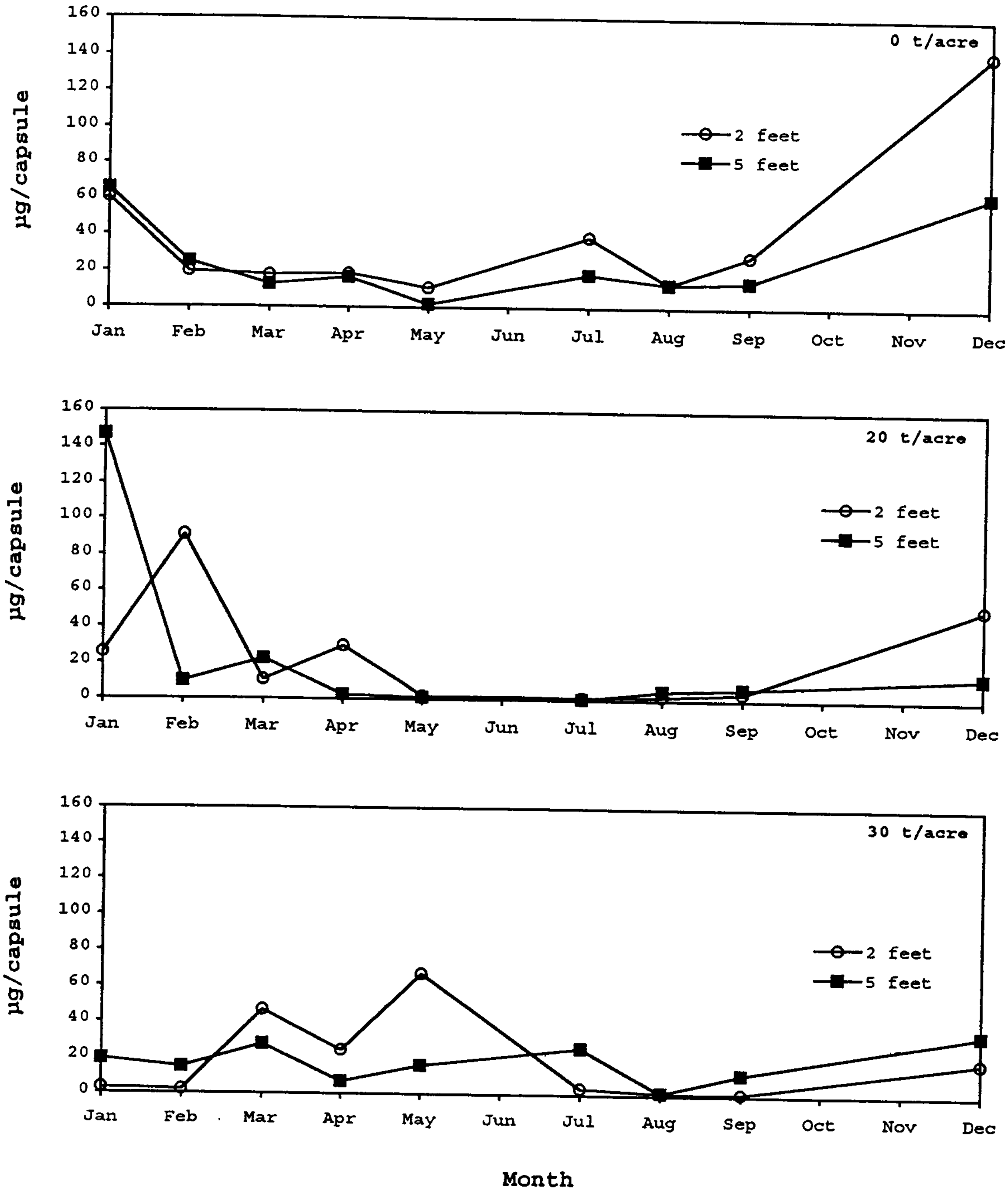


Figure 23. Resin Capsule Results for Phosphorous

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

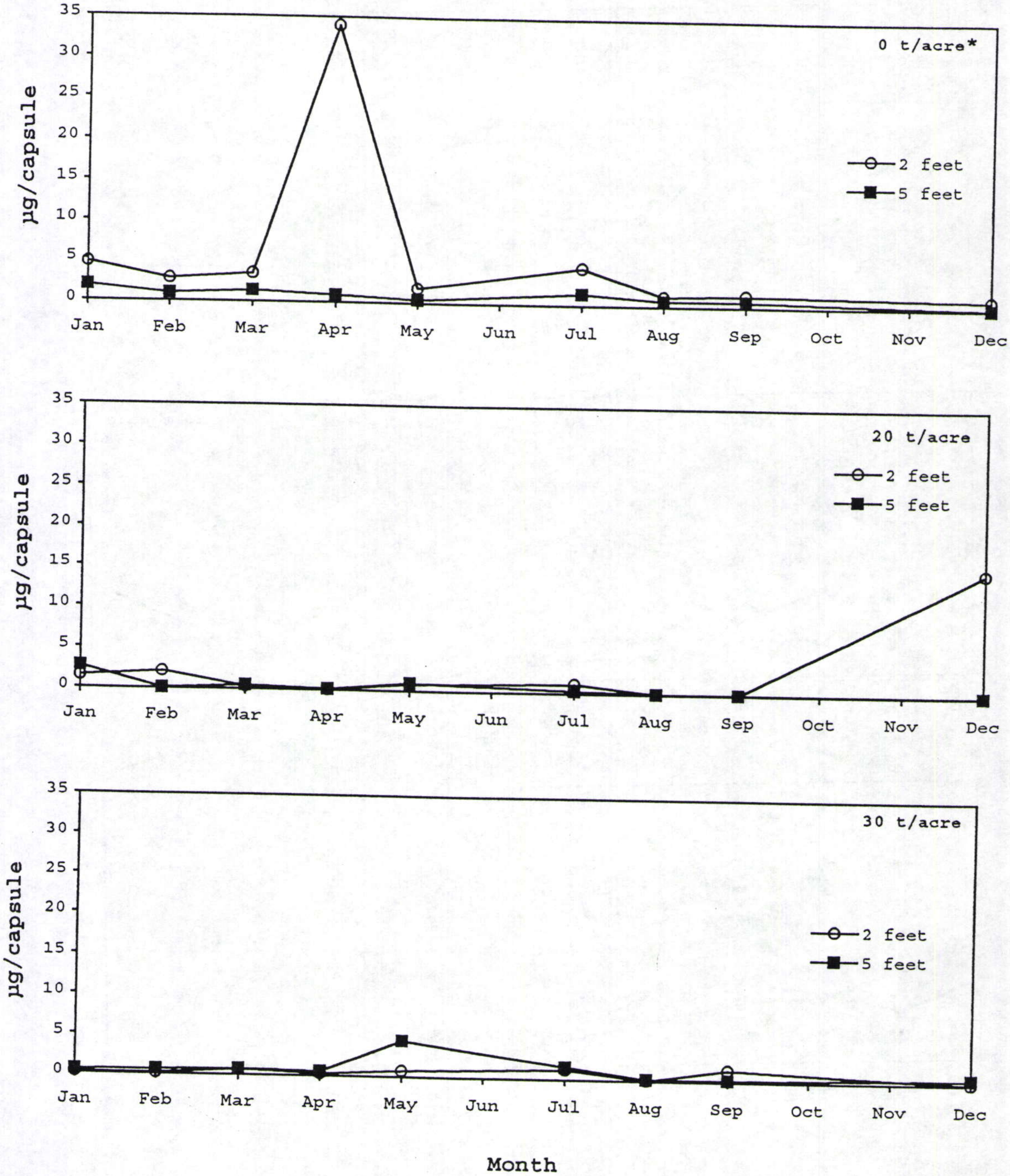


Figure 24. Resin Capsule Results for Nickel

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

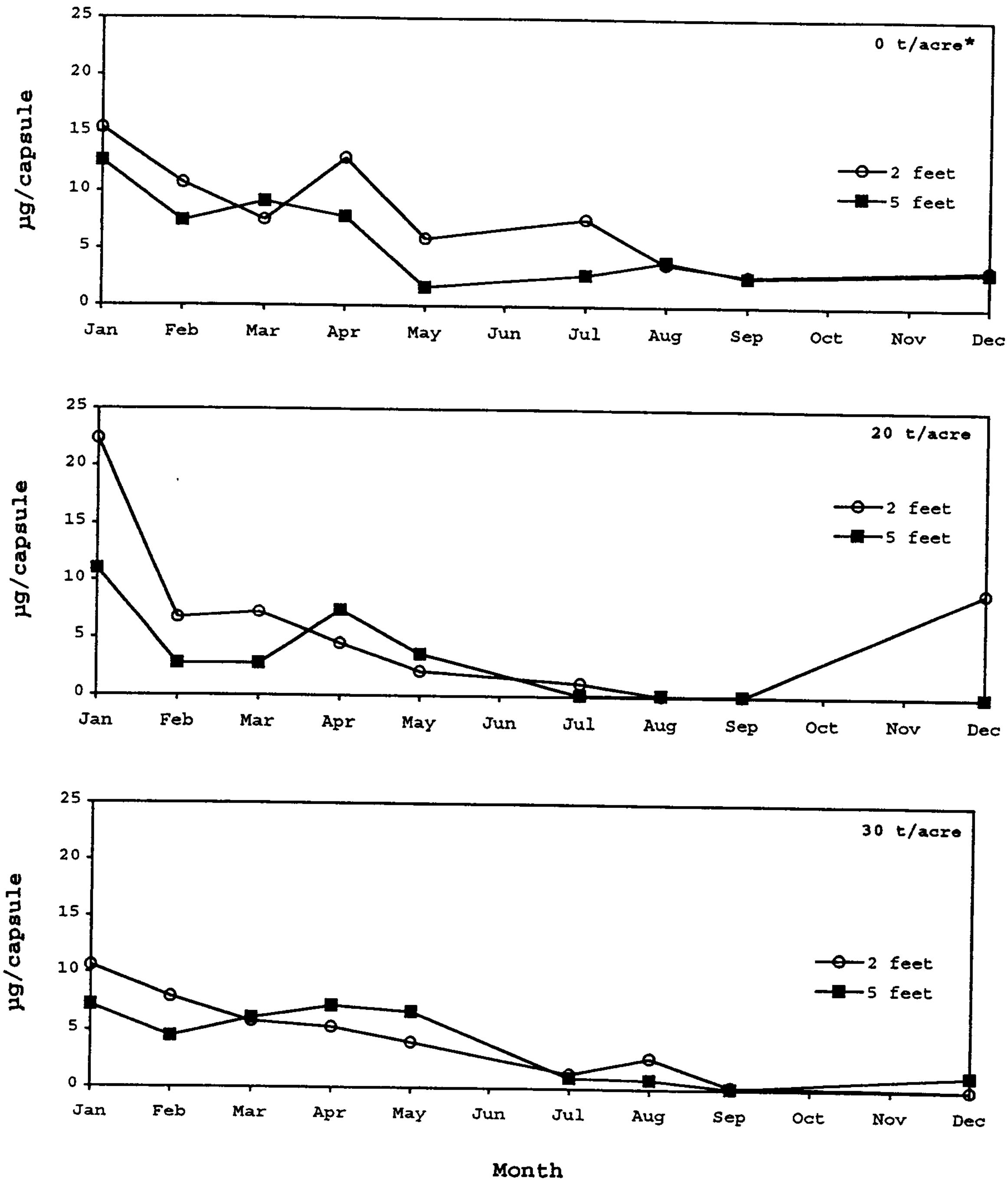


Figure 25. Resin Capsule Results for Zinc

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

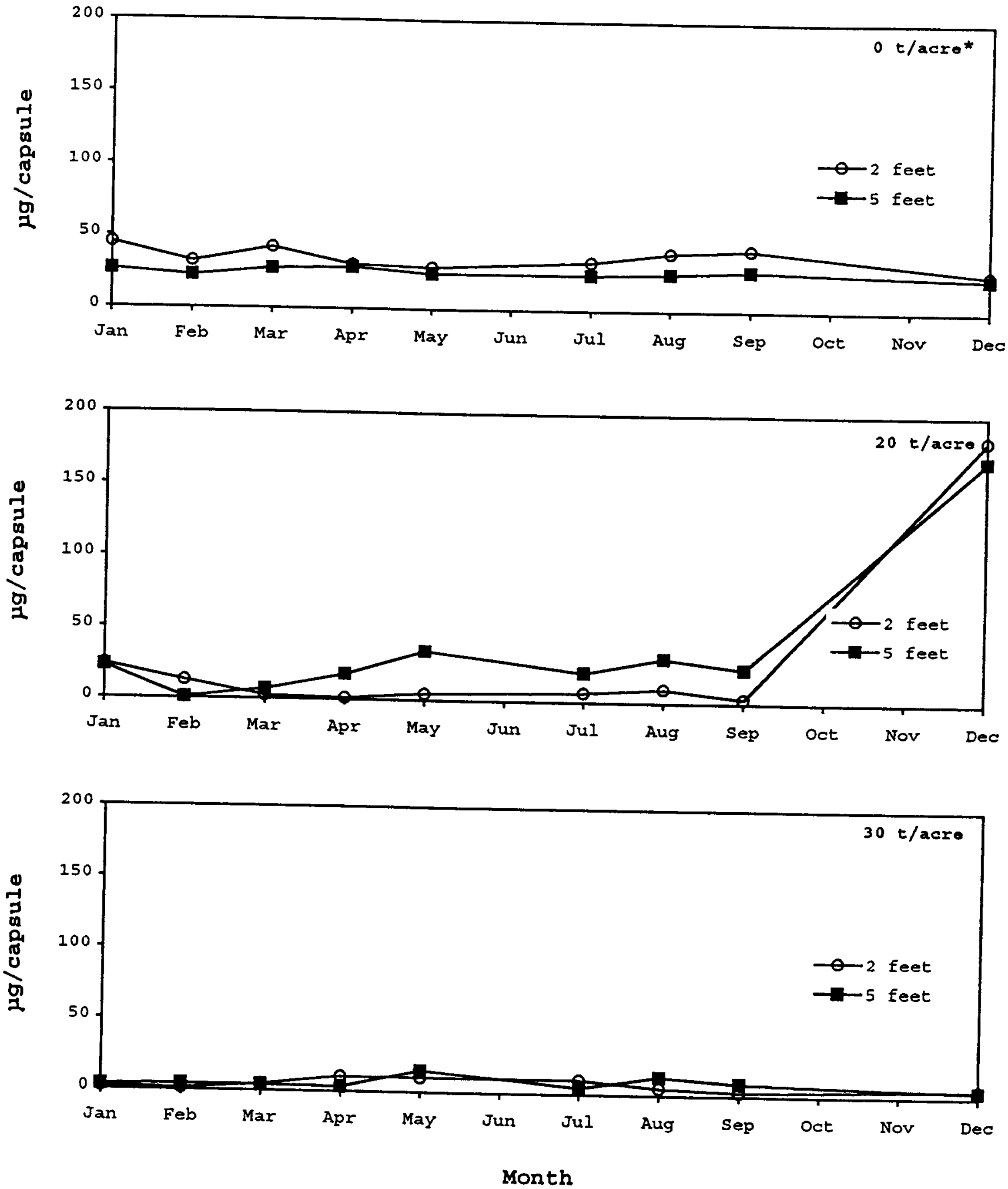


Figure 26. Resin Capsule Results for Manganese

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

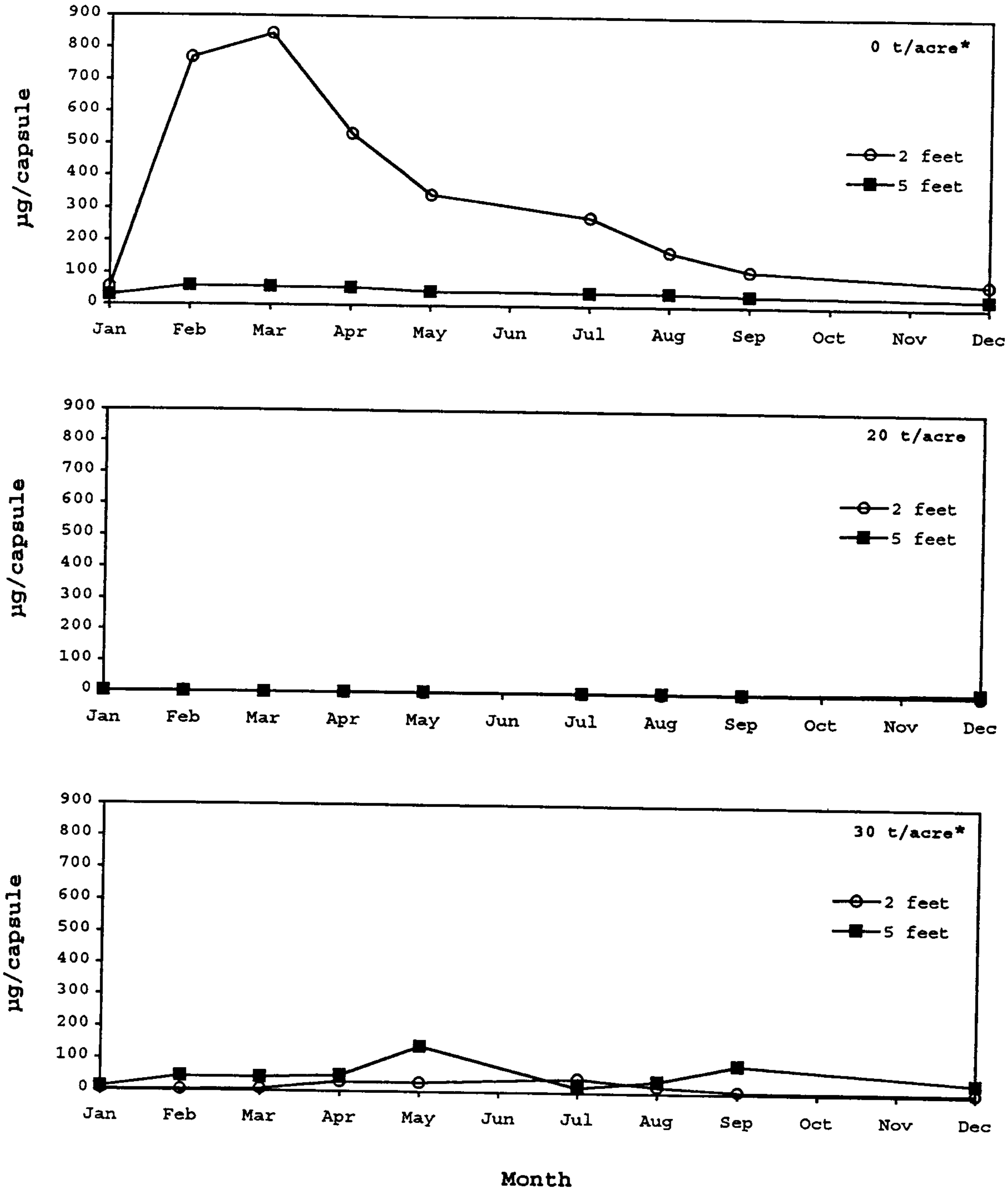


Figure 27. Resin Capsule Results for Molybdenum

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

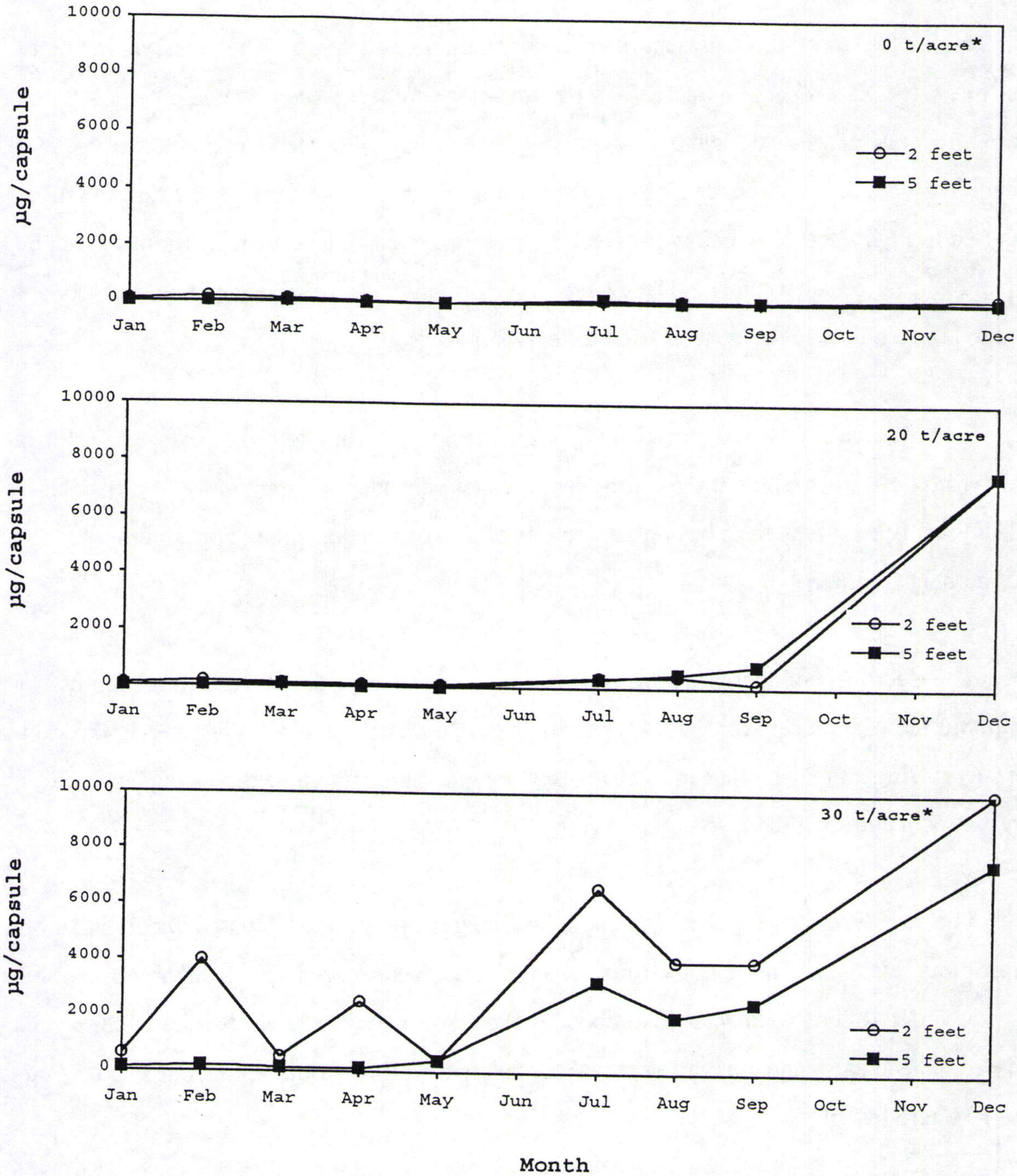


Figure 28. Resin Capsule Results for Nitrate-Nitrogen

* Significant differences between 2 foot and 5 foot depths for the particular treatment at 0.05 significance level, given by Paired t-test

10.4 Lysimeter Results

Figures 29 through 42 present the lysimeter data taken in 1995. The pressure-vacuum lysimeters were placed in the 0 t/acre, 20 t/acre and 30 t/acre test plots. It should be noted that an apparent reversal of vertical scale occurs with Figs. 32 through 42 when compared to Figs. 29 through 31. This apparent change is due to a transformation of scale for Figs. 32 through 42, compared to Figs. 29 through 32, which had no transformation. The transformation is given by, -log[(mg/L)/(molecular weight)]. This type of transformation is a relatively common practice, and was done to standardize the vertical scale for easy comparison.

The pH levels remained essentially constant, near 7.0, throughout the year, except for the lysimeter in the 20 t/acre plot at the 2-foot depth, which remained constant close to 5.0. This particular instrument may have been placed in one of the localized acidified zones in the impoundment (Fig. 29).

The electrical conductivity remained essentially constant in all plots and at all depths throughout the year, except for the 2-foot depth in the 30 t/acre test plot. The jump in the value from July to August may be related to changes in the moisture content as the tailings material dried out, concentrating the levels of salts (Fig. 30).

The dissolved oxygen, as measured in the tailings pore water, fluctuated widely in all of the test plots (Fig. 31). This is not surprising, as the dissolved oxygen level is highly susceptible to a wide variety of environmental conditions. It should also be noted that the dissolved oxygen increased in a similar manner as the electrical conductivity at the 2-foot depth from July to August in the 30 t/acre test plot.

Sodium, Ca, Mg, and K remained at essentially the same levels on all test plots, at both depths, throughout the year (Figs. 32 through 35). However, Mg exhibited a drop in value from July to August at the 2-foot depth in the 30 t/acre test plot, indicating uptake by plants as the growing season began (Fig. 34).

Arsenic and iron both remained essentially constant throughout the year (Figs. 36 and 37). Arsenic dropped in value early in February, but returned to, and remained at the higher level in March (around 7 mg/L). Thus, the February As results may have been spurious (Fig. 36). Copper remained essentially constant throughout the year (Fig. 38). However, the level of Cu is higher at the 2-foot depth in the 20 t/acre test plot. This probably was due to the lower pH at this location (Fig. 29). Given the future importance of the use of both the resin capsules and the lysimeter data, a recommendation is made that another instrumentation set be placed in another control plot.

The levels of Se remained essentially constant, except that a drop in value occurred from July to August at the 2-foot location in the 30 t/acre test plot. The levels of Zn remained between 5 to 6 mg/L throughout the year. A drop from 6 to 5 mg/L occurred in May, which may indicate uptake of Zn by plants as the growing season began (Fig. 40). The level of Mn remained essentially between 4 and 5 mg/L throughout the year (Fig. 41). The sulfate levels remained essentially constant between 1 to 2 mg/L throughout the year (Fig. 42).

The lysimeter data indicated that the application of biosolids did not increase the levels of metals or other measured chemical species in the tailings water.

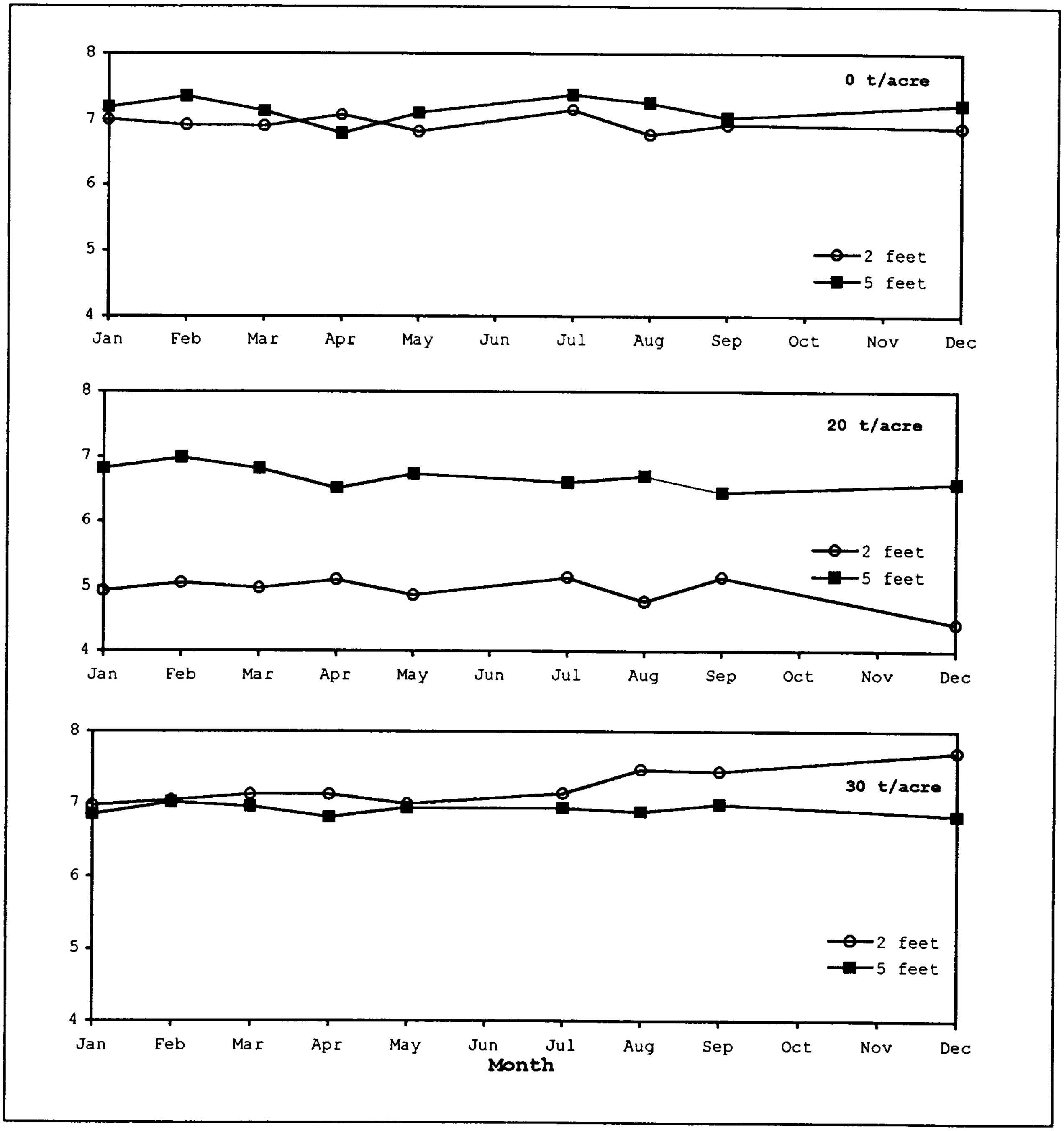


Figure 29- Lysimeter Results for pH

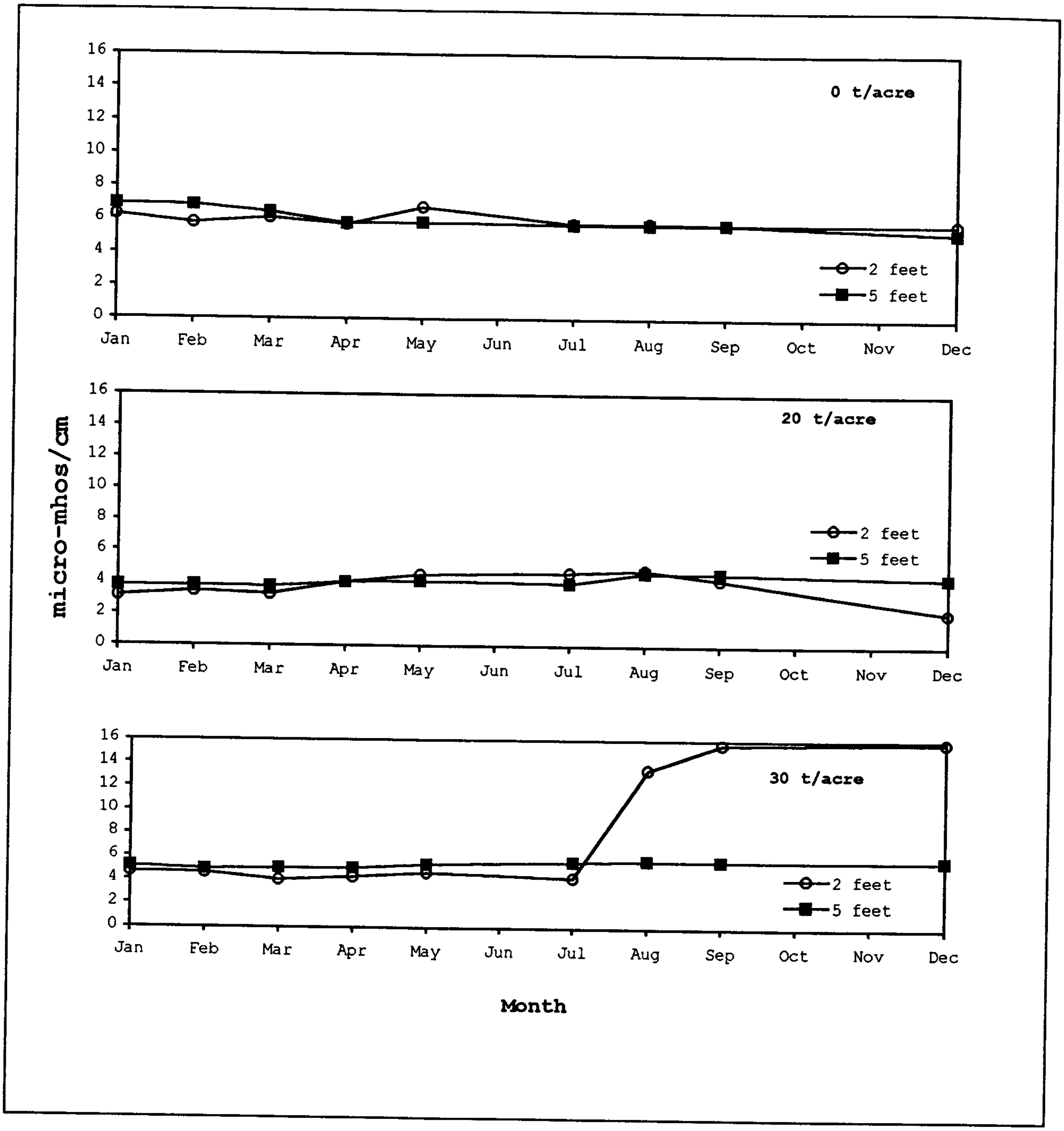


Figure 30- Lysimeter Results for Electrical Conductivity

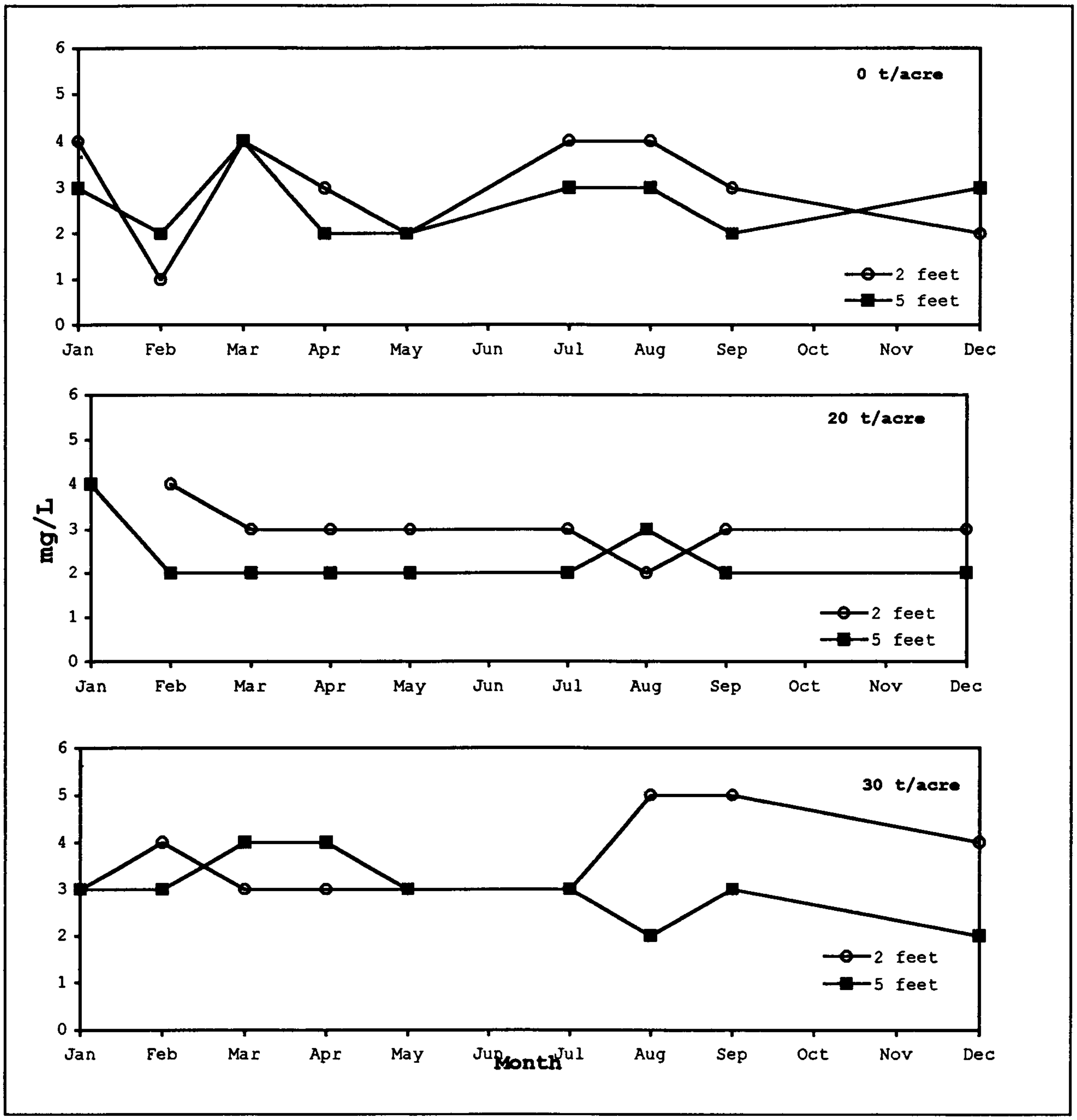


Figure 31 - Lysimeter Results for Dissolved Oxygen

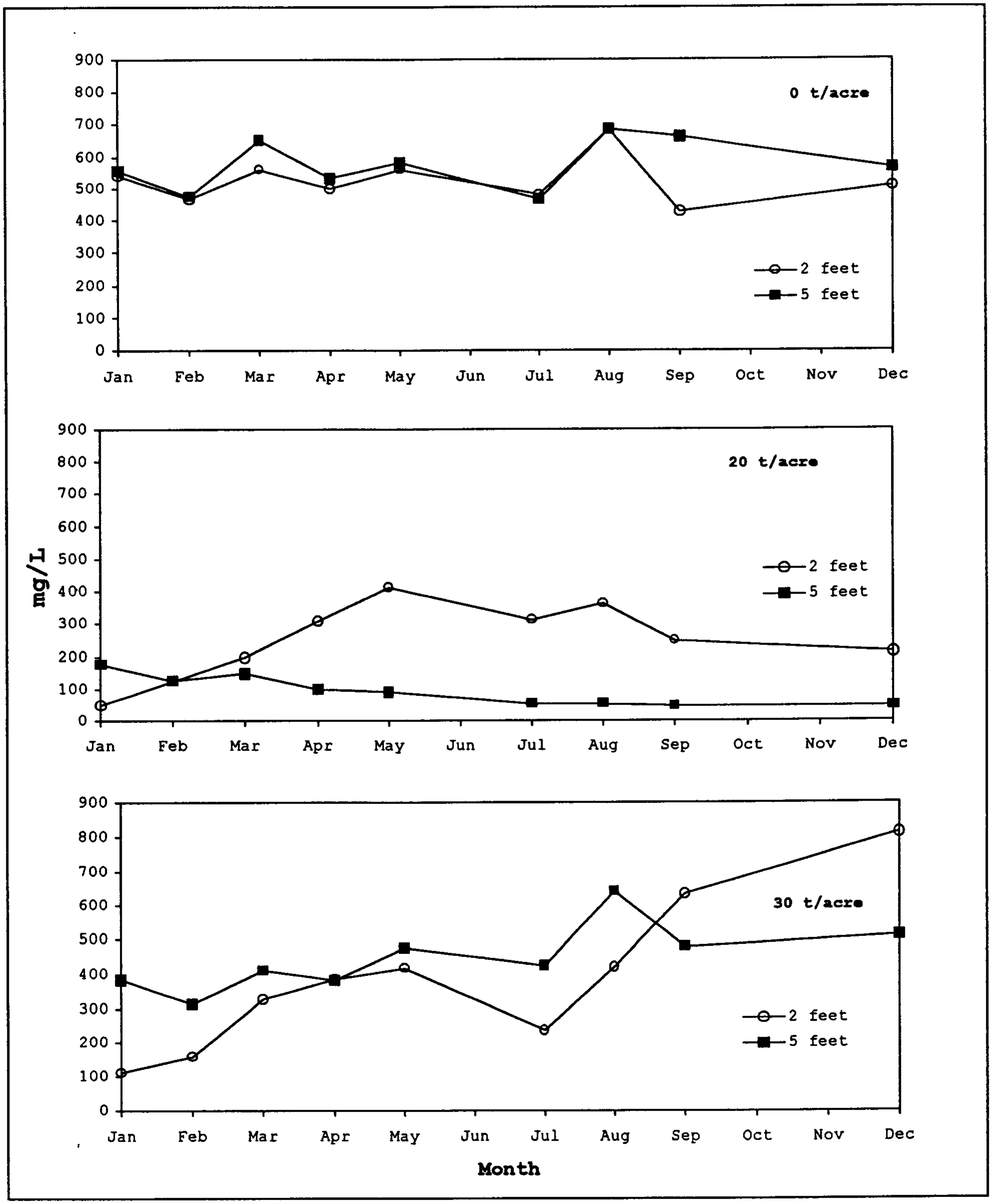


Figure 32 - Lysimeter Results for Sodium

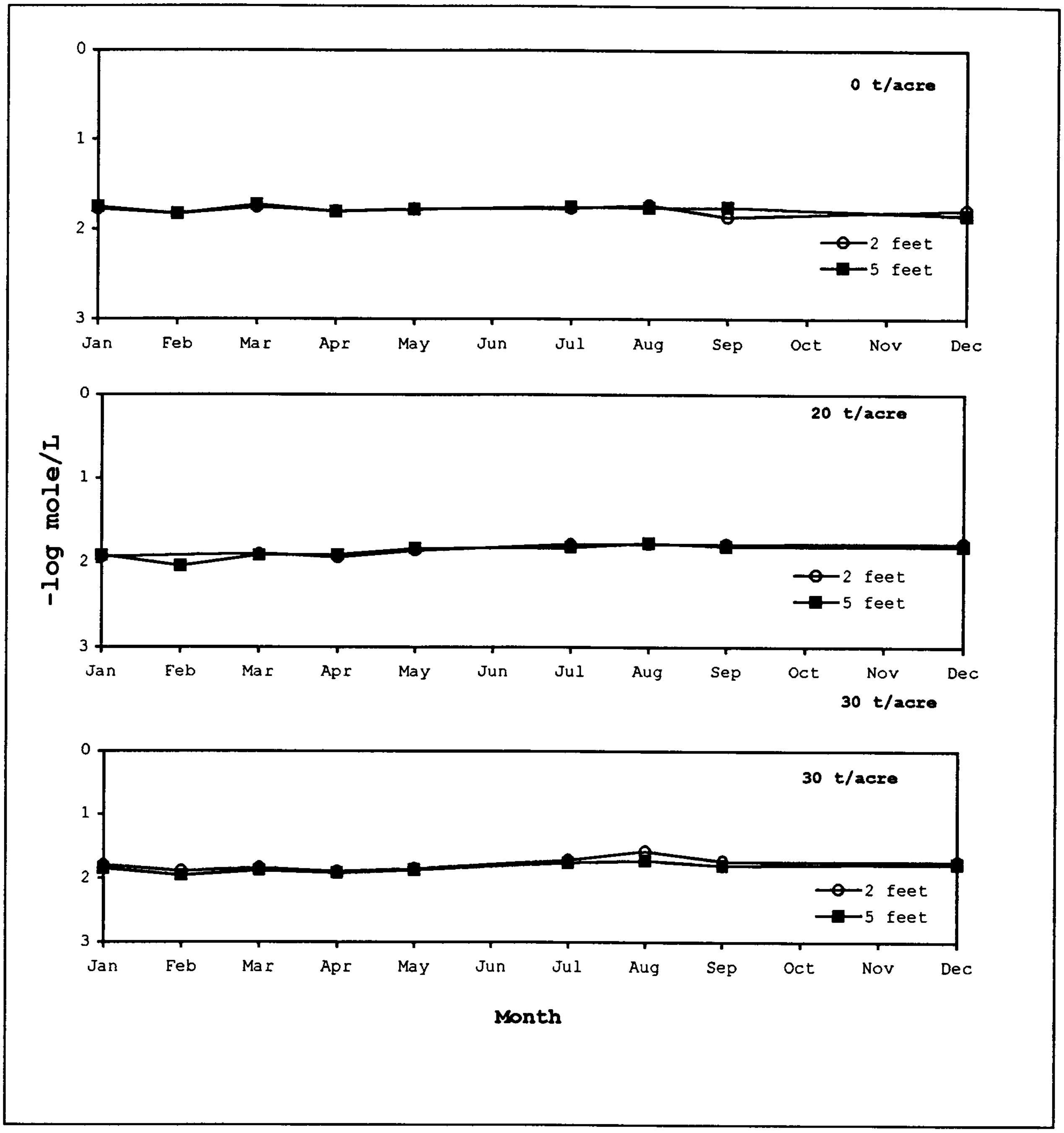


Figure 33 - Lysimeter Results for Calcium

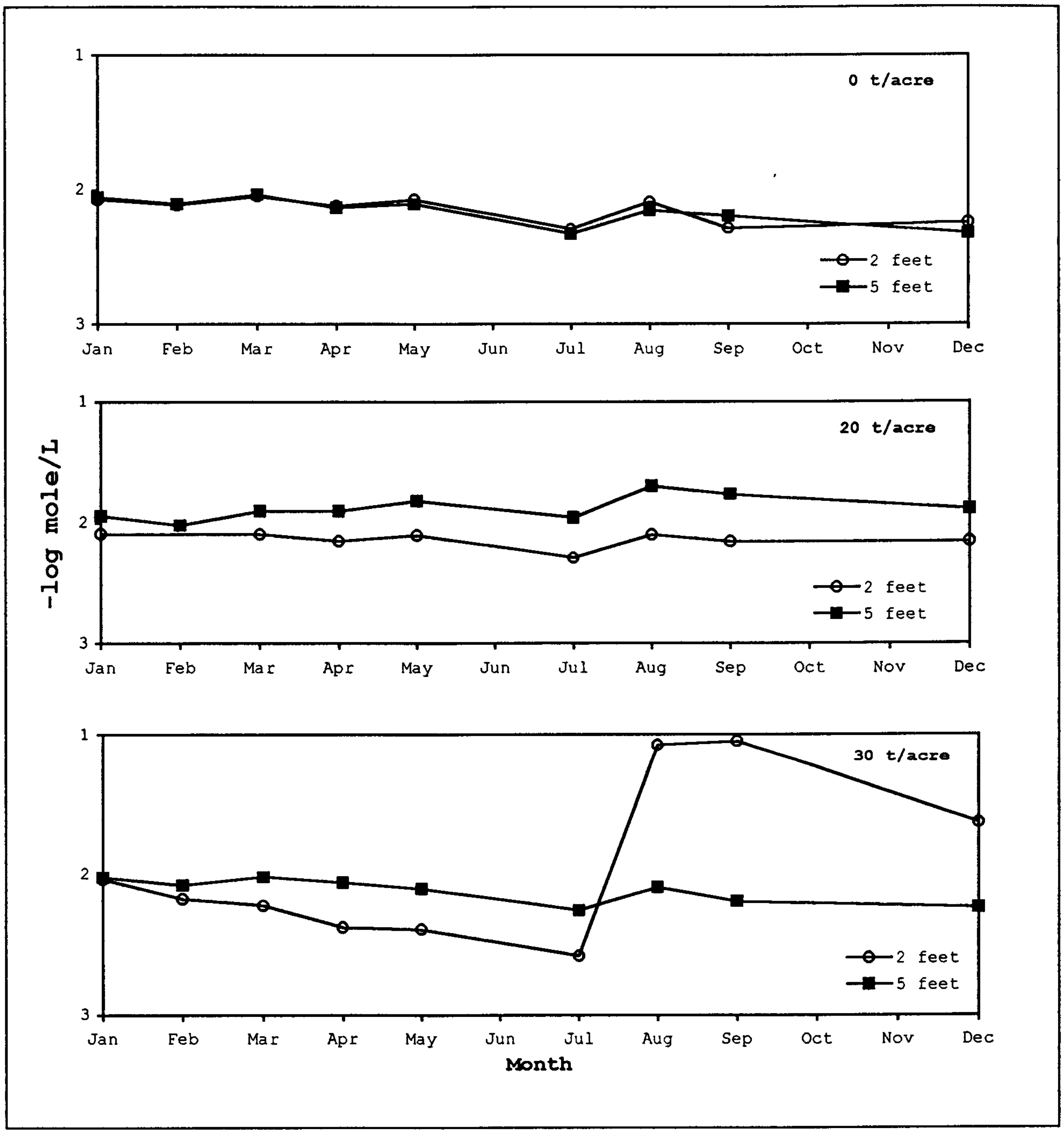


Figure 34 - Lysimeter Results for Magnesium

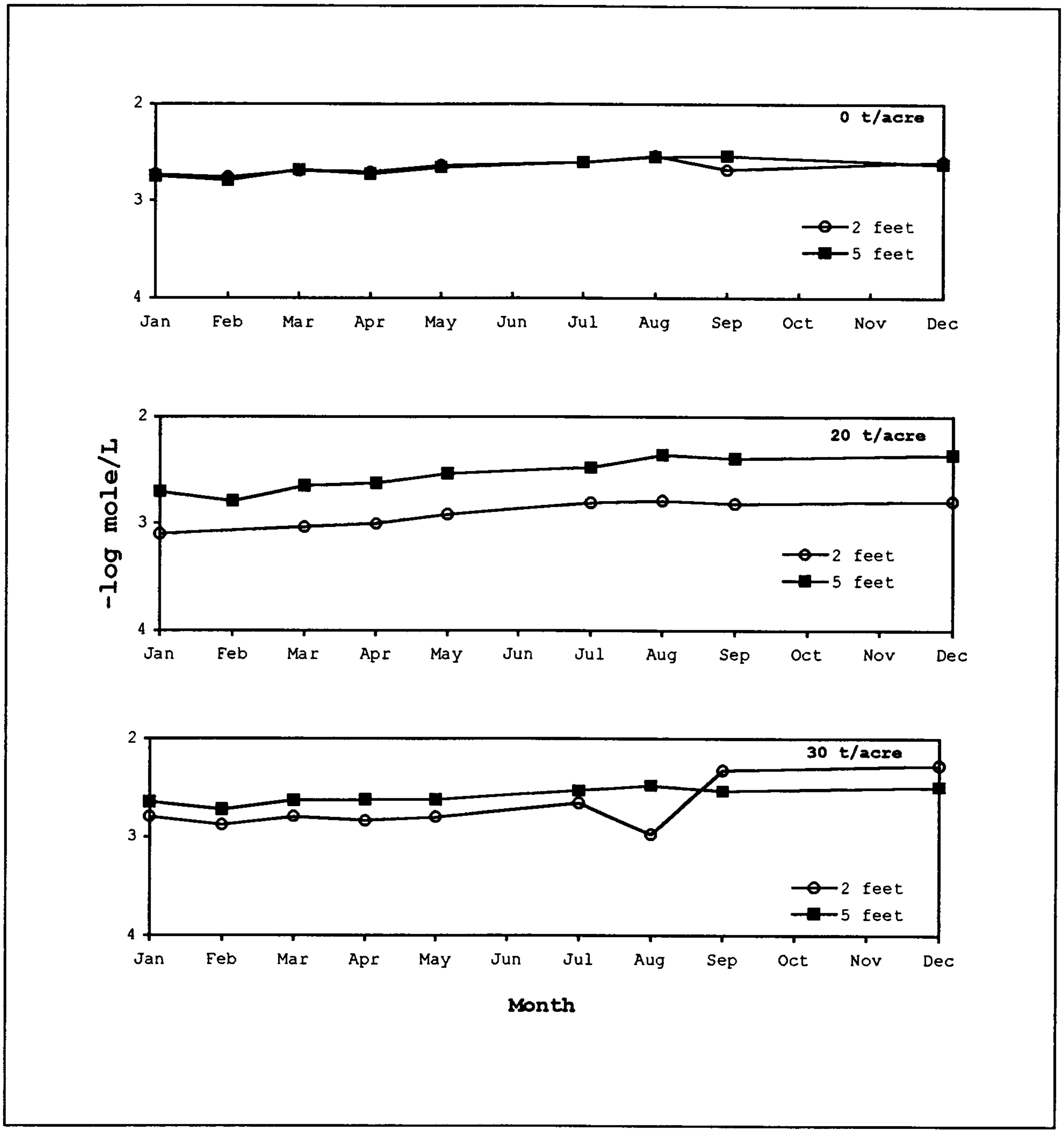


Figure 35 - Lysimeter Results for Potassium

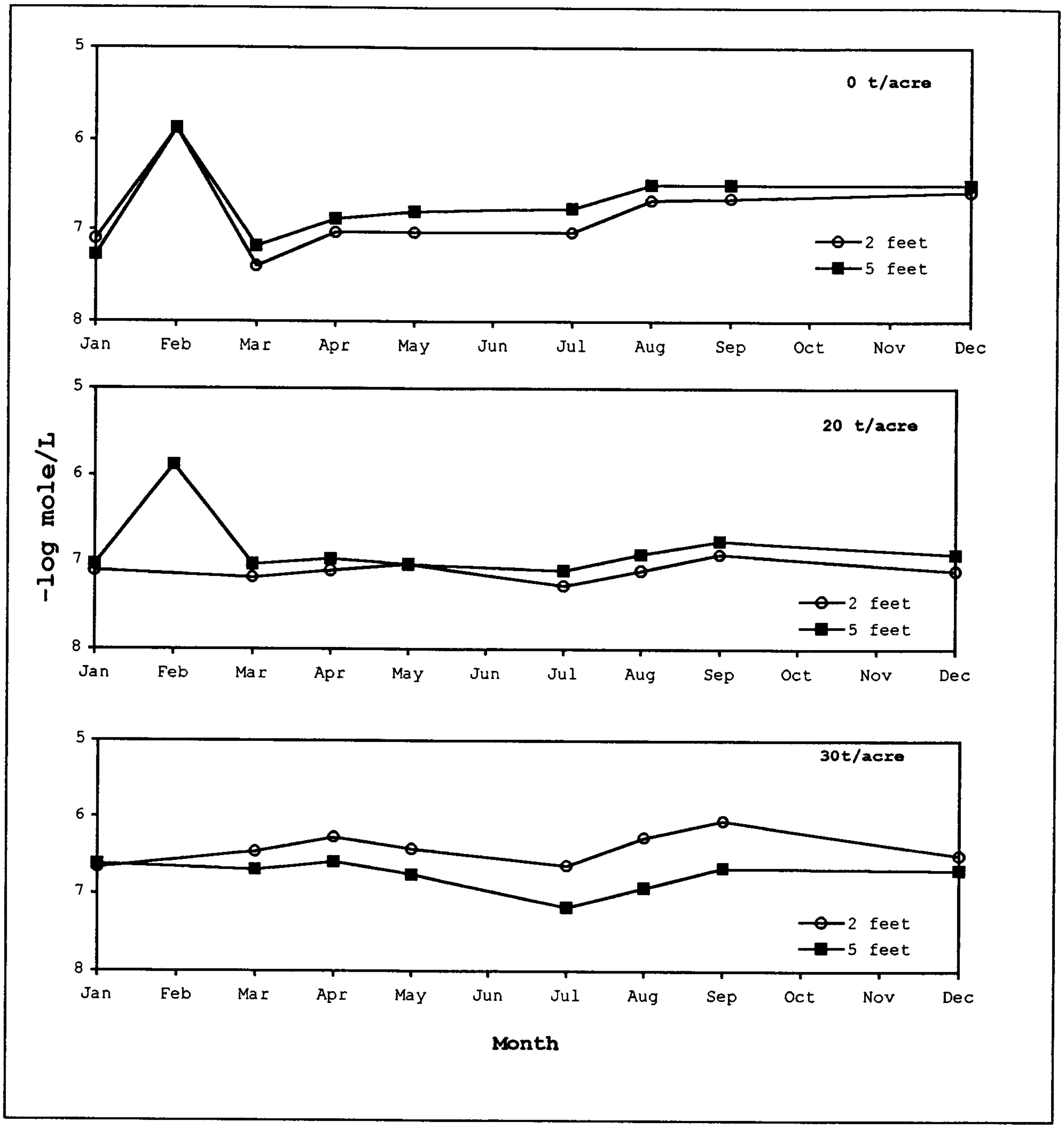


Figure 36 - Lysimeter Results for Arsenic

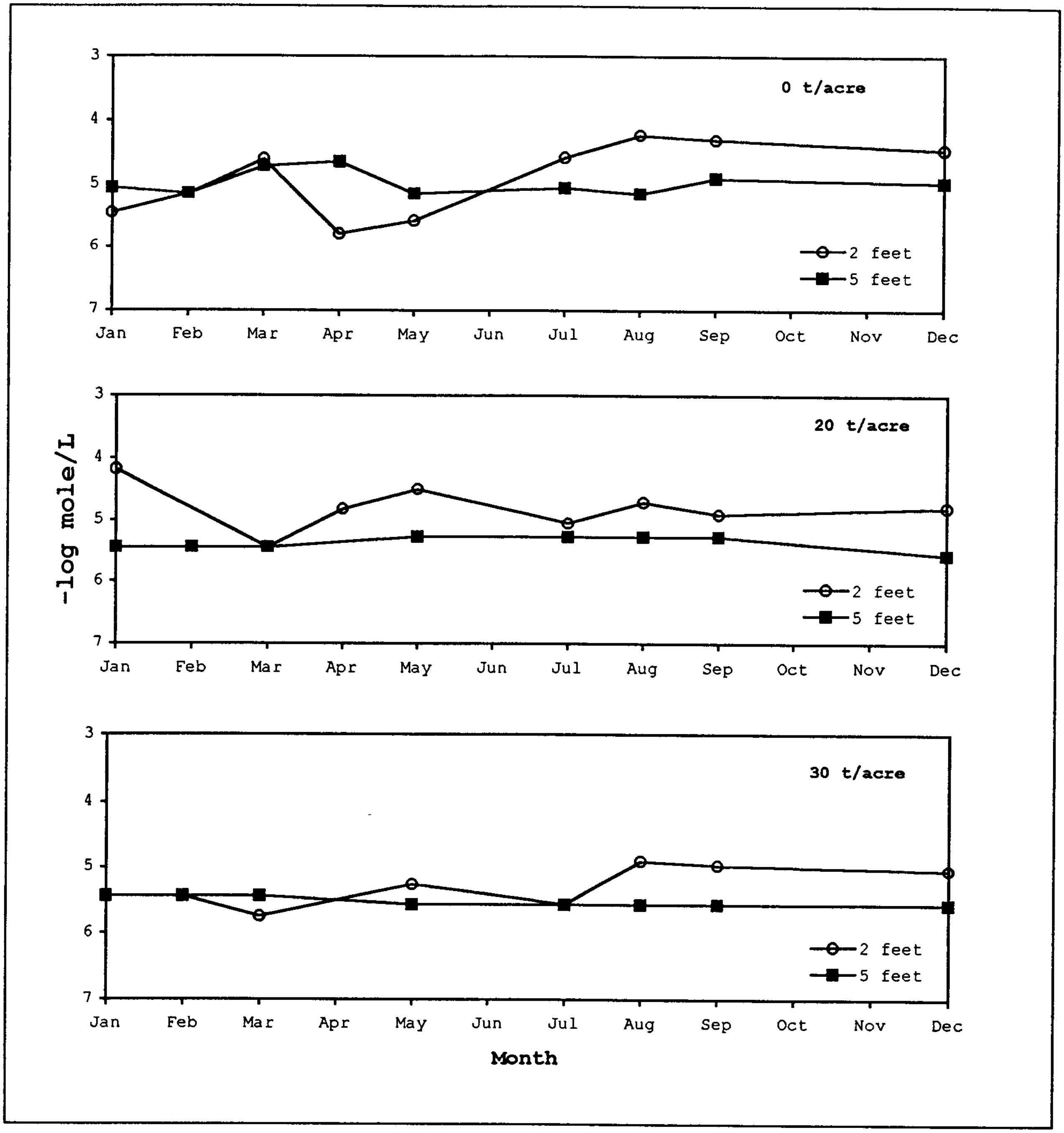


Figure 37 - Lysimeter Results for Iron

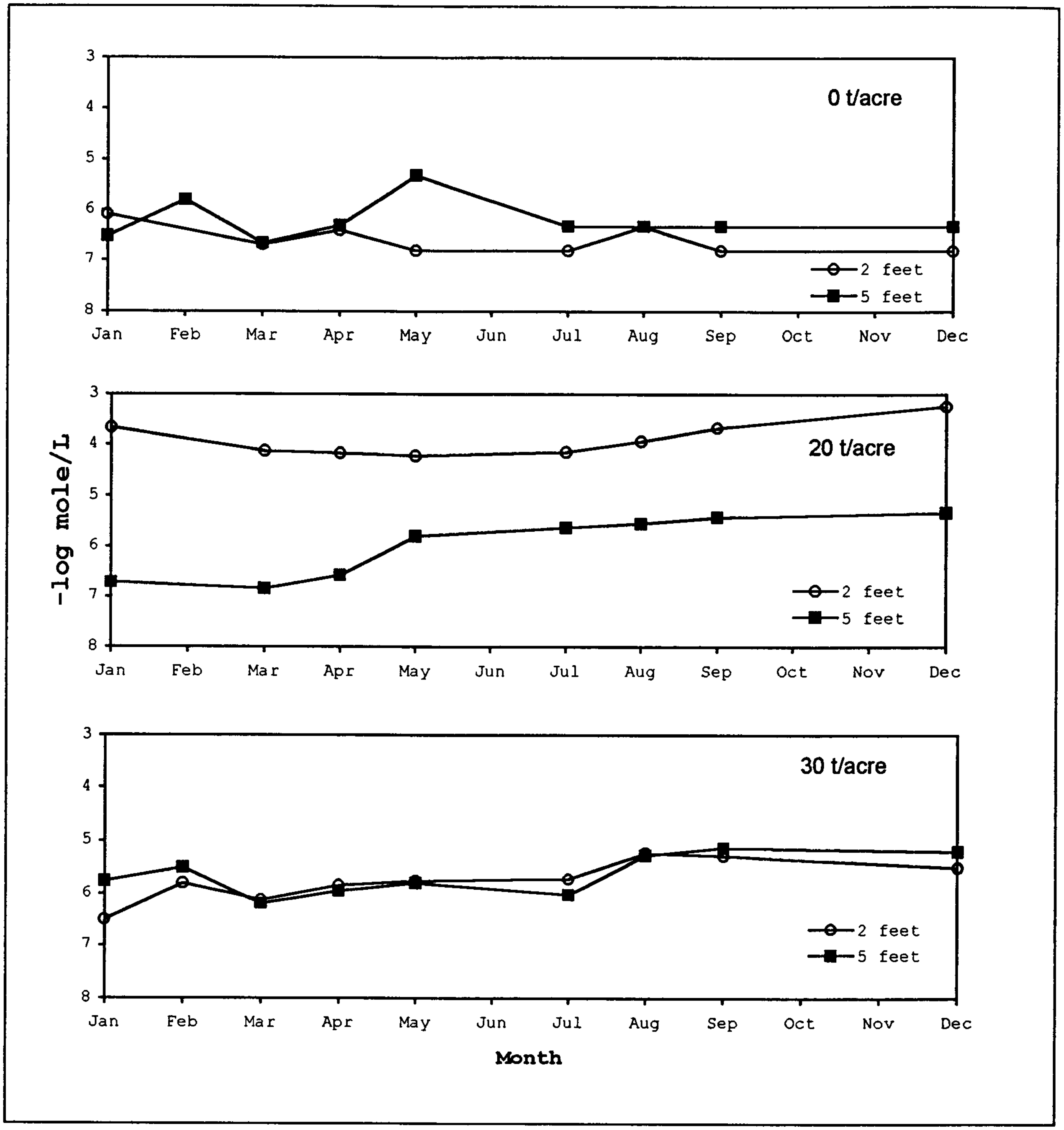


Figure 38 - Lysimeter Results for Copper

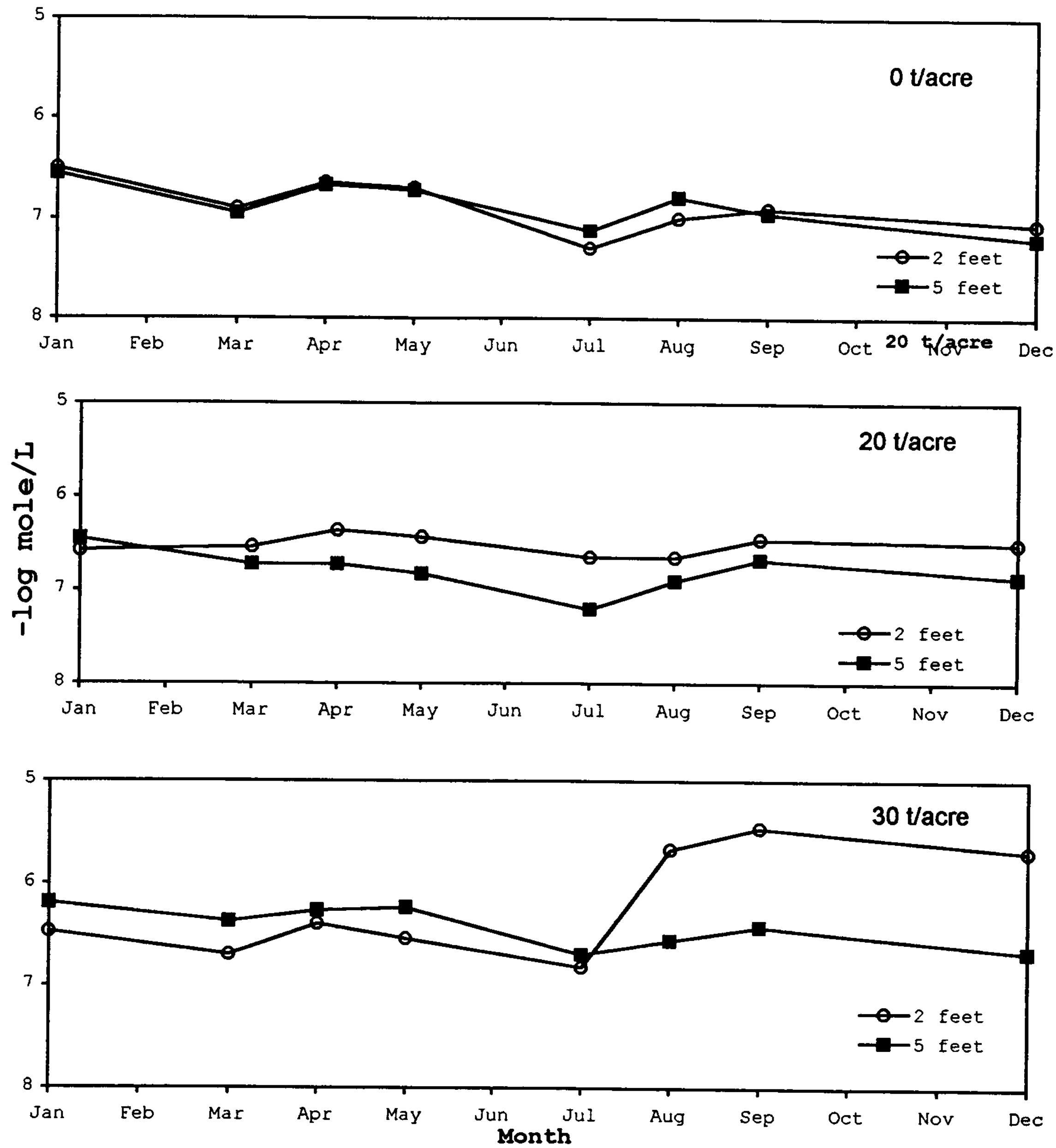


Figure 39 - Lysimeter Results for Selenium

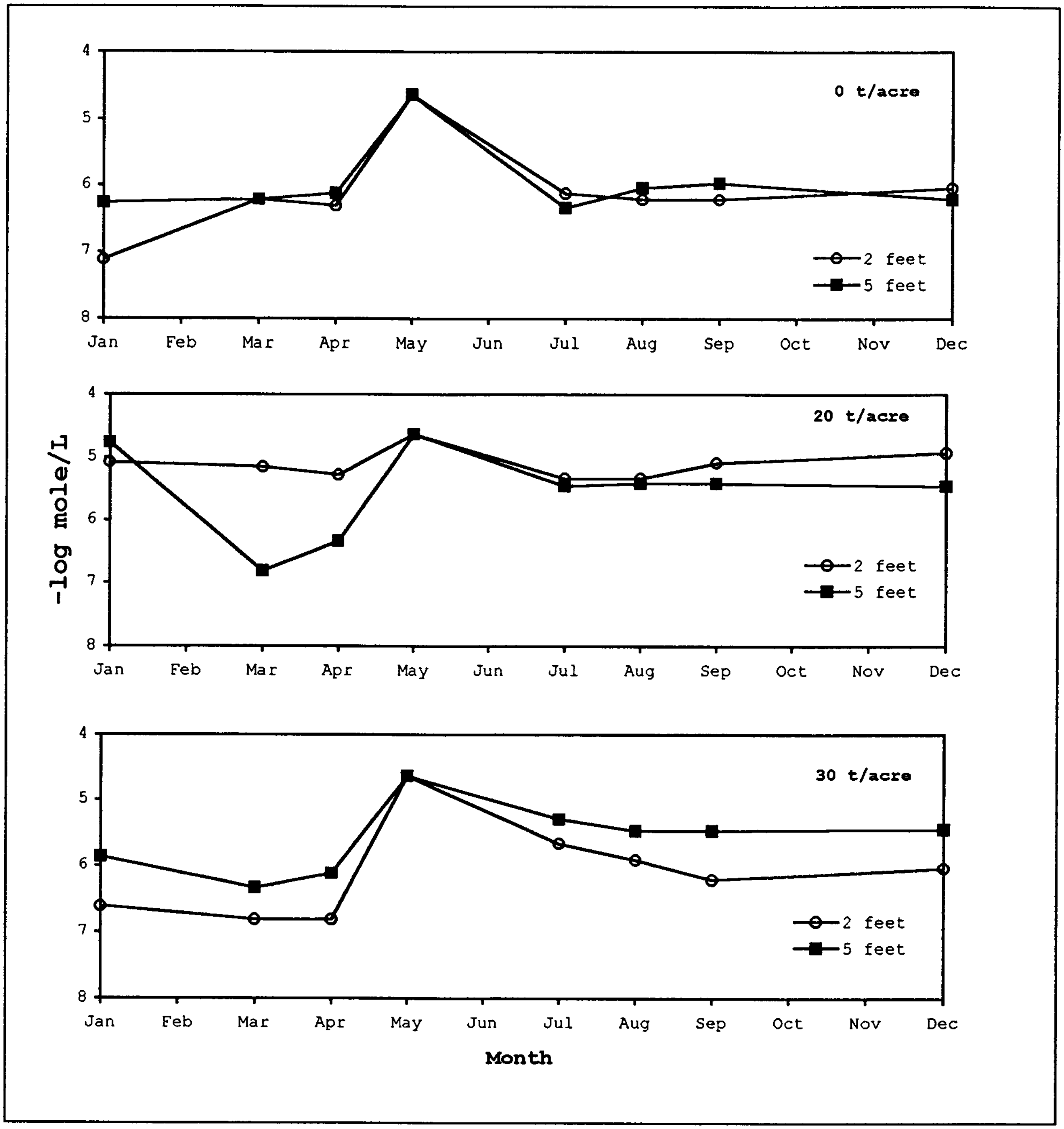


Figure 40 - Lysimeter Results for Zinc

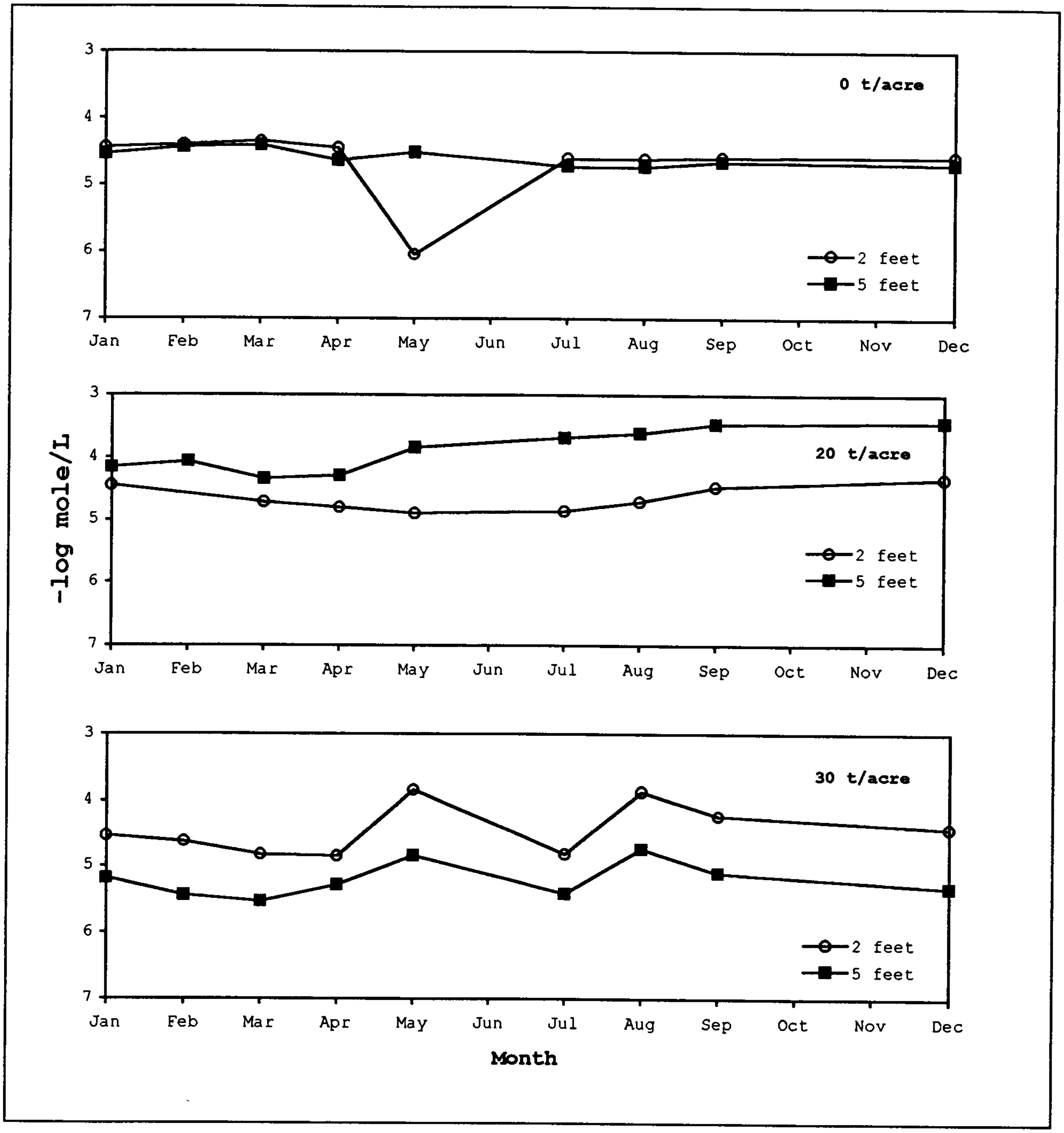


Figure 41 - Lysimeter Results for Manganese

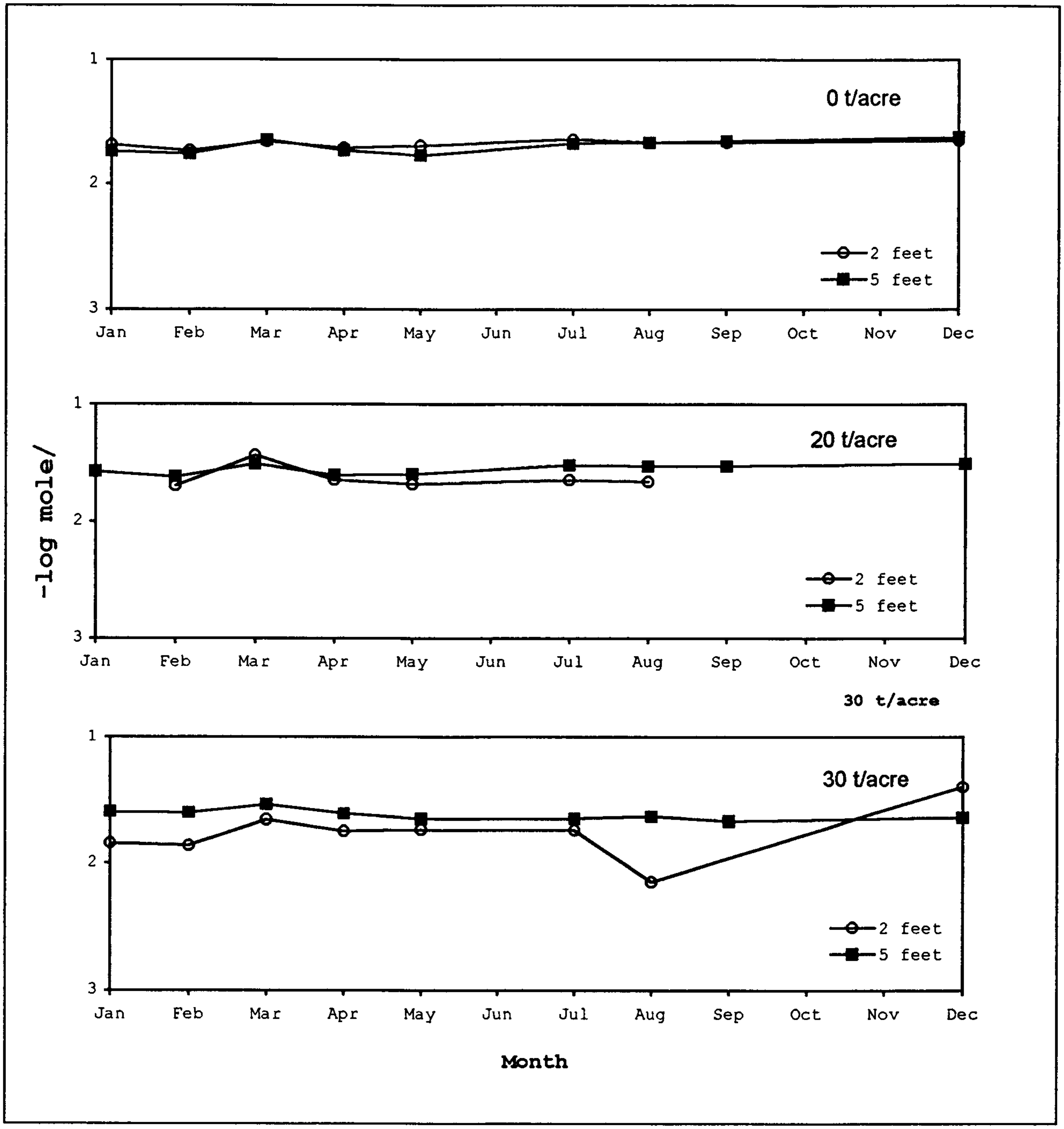


Figure 42 - Lysimeter Results for Sulfate

10.5 Biomonitoring Results and Discussion

A positive growth response of planted test species, namely winter rye, sheep fescue, tall wheatgrass, yellow sweet clover, and alfalfa to biosolids addition was apparent within the first two months after planting and throughout the growing season (Fig. 43). Statistically significant differential biomass responses were observed on all test plots where biosolids were added when compared to the control plots (Table 8). Biomass production increased significantly with each increase in the biosolids application rate.

Table 8. Comparison of mean biomass results by additional amendment and by biosolids application rates within each test site.

Appl. Rate (dry tons/acre)	Site No. 1 (with $CaCO_3$)	Sites No. 2 & 4 (biosolids only)	Site No. 3 (with wood)	Site No. 3B (Magna biosolids)	Mean
0	14.7Aa*	29.4Aa	46.4Ab	9.5Aa	24.4A
10	316.5Ba	283.0Ba	217.0Bb	83.4Bc	225.0B
20	327.9Ba	295.0Ba	223.8Bb	193.3Cb	260.0C
30	333.8Ba	375.7Cb	289.6Cc	289.2Dc	322.1D
Mean	248.2a	245.8a	194.2b	143.9c	

*Means followed by different capital letters in the same column (additional amendment) and by different small letters in the same row (biosolids application rate) are significantly different at α=0.05 by the Student-Newman-Keuls Multiple Range Test.

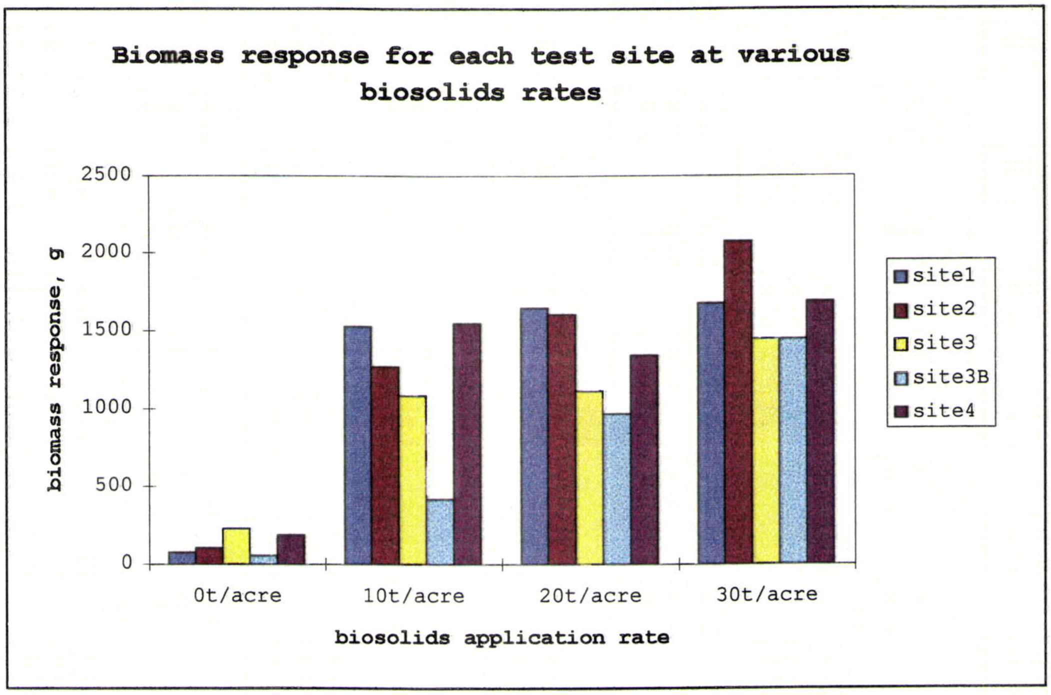
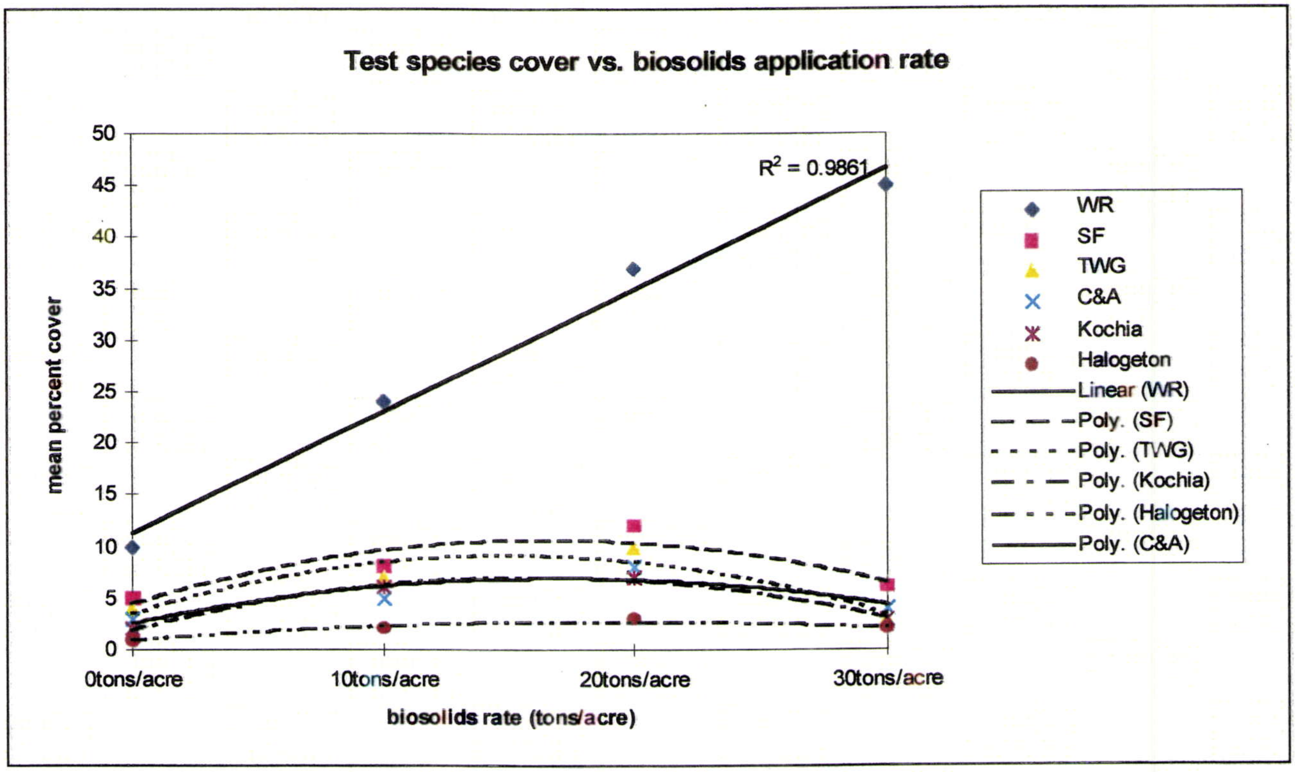


Fig. 43 - Site-specific biomass production at various biosolids rates

Test site No. 1 (with an additional amendment of limestone) and test site No. 2 and 4 (CVWRF biosolids only) had comparable mean levels of biomass production, followed by test site No. 3 (with an additional amendment of wood residue), followed by test site No. 3B (Magna biosolids only). The lower mean level of biomass production for test site No. 3 may have been due to higher rates of nitrogen utilization by microbes to mineralize the additional carbon supplied by the wood residues. The aerobically-treated Magna biosolids had typically lower levels of nitrogen than the anaerobically-digested CVWRF biosolids, which may have contributed to the relatively low biomass production in site No. 3B when compared to the other sites where biosolids were added.

Biosolids amendment increased dramatically the growth of winter rye (Fig. 44). It exhibited the greatest overall mean percent cover (29 %), followed by sheep fescue (7 %), and kochia (*Kochia* sp.) (5 % as an invasive weed). There was a statistically significant increase in biomass production with increasing biosolids application rate for winter rye, sheep fescue, and kochia. In contrast, other test species did not display any statistically significant difference in growth, including halogeton (*Halogeton glomeratus)*, also an invasive weed. These results may be explained in part by the apparent dominance of winter rye, which was planted at a rate which exceeded the planting rates of the other test species by a factor of eight. At this time, it is unclear how this particular species will behave during subsequent years of the study, but it might be advisable to reduce the planting rate for winter rye in comparison to other species such as sheep fescue, tall wheatgrass and the legumes, especially when biosolids is used as a soil conditioner.

All test species were examined for any kind of correlation between biosolids application rate and percent cover using either the Pearson product moment correlation or the Spearman rank order correlation test. A positive trend was established for winter rye, which produced the greatest biomass and percent cover of all the species planted. Winter rye production increased significantly with increasing biosolids application rate (Fig. 44). It should be noted that the ratio of all other test species to winter rye dropped off at the 30 ton/acre application rate. This may have been due to the competitiveness of winter rye at the higher biosolids application rate.



WR = winter rye, SF = sheep fescue, TWG = tall wheatgrass, C & A = clover and alfalfa

Fig. 44 - Percent cover at various biosolids rates

The plant tissue concentrations of metals, except for Cu, in the three species tested (winter rye, sheep fescue, and tall wheatgrass) were within normal limits (Logan and Chaney, 1983, and Mendel and Kirkby, 1987). The level of copper in the tailings was initially high (Table 5). Thus the higher level of copper found in the plant tissue was not due to the addition of biosolids. The highest levels of Cu was seen in the tall wheat grass, followed by sheep fescue, then by winter rye. Table 9 lists the mean levels of Cu for the three test species. There was also a decreasing trend in plant tissue concentrations of Cu with increasing biosolids application rate.

Table 9 - Plant tissue copper levels (mg/kg)

Plant Species	Biosolids Application Rates			
	0 ton/acre	10 ton/acre	20 ton/acre	30 ton/acre
Winter Rye	28.8	21.8	18.9	20.7
Sheep Fescue	54.9	45.1	46.1	39.2
Tall Wheat Grass	101.7	135.4	53.4	35.3

11 Conclusions

The analysis of tailings characteristics as they relate to plant growth showed that pH and electrical conductivity are adequate in all test sites. Other parameters that are important for sustainable plant growth such as organic matter content, and plant available nitrogen and phosphorus, increased with the increased biosolids application rate.

Data collected from tailing samples taken at depth and from the instrumentation array indicated that there is not a problem with metals leaching from the biosolids. Monitoring for nitrate should continue, however. Both the resin capsules and the lysimeters should still be used for long-term monitoring of chemical species including metals. One additional instrumentation set should be added in another control plot because the present control plot set is apparently located in an acidified zone.

The dominant species found on the test sites was winter rye which out-competed all the other plant species. It is still unclear how this particular species will behave during the summer of 1996 but it might be advisable to reduce the planting rate for winter rye with comparison to other species such as sheep fescue and tall wheatgrass, and especially the perennial species. This suggestion would apply whenever biosolids is used as a tailings conditioner.

12 Visual Overview of the Project

Figures 45 through 50 present a visual overview of plant growth which illustrates the differences in plant growth between the different application rates of biosolids. Please refer to the Interim Report (McNearny, 1995) for a chronological sequence of photographs describing the work performed for the project.

Figure 45- Overview of Test Site No. 1 from the east

Figure 46- Site No. 2, Control plot in foreground, 20 t/plot in background, 30 t/acre plot to the left

Figure 47- Site No. 2, Control plot to the left, 30 t/acre plot to the right, acidity zone in the center

Figure 48- Overview of Sites No. 3 and 3b, looking east

Figure 49- Site No. 3, Control Plot in foreground, 30 t/acre plot in background

Figure 50- Site No. 4, Control plot in foreground, 10 t/acre plot in background

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